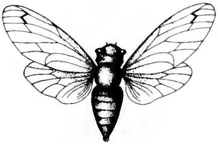

INSECTS

THEIR STRUCTURE & LIFE

A PRIMER OF ENTOMOLOGY

BY

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To

MY FATHER AND MOTHER

We may say many things, yet shall we not attain;

Many things are hidden greater than these;
For we have seen but a few of His works.

ECCLESIASTICUS, xliii 27, 32.

PREFACE

Not one, even of the many books made in these days, is likely to be thought superfluous by its author. And in spite of—to a great extent indeed because of—the thousand and more original works on Insects now published yearly, it seems that the student has need of a small inexpensive, English book, sketching in outline the whole subject of entomology.

Such a volume as this is necessarily for the most part a compilation. To save space, the names of authorities are not mentioned in the text; but reference figures in heavy type call attention to the bibliography at the end of the book, where a list of works consulted by the author, or likely to be of special use to the student, will be found. Particular acknowledgment, however, is due to Professors Miall and Denny, whose admirable monograph on the Cockroach has been largely used in the opening chapter; to Professor A. S. Packard, whose recent Text-book has been invaluable both as a store of facts and a guide to the literature; and to Dr D. Sharp, whose contribution to the "Cambridge Natural History," has been especially useful in preparing the systematic part of this book. Much help has also been derived from the systematic writings of Colonel Bingham, Canon Fowler, Sir G. F. Hampson, Mr W.

F. Kirby, Mr E. Saunders, and the late Dr J. R. Schiner.

My best thanks are further due to Professor L. C. Miall for his generous kindness in lending a large number of blocks used for illustrating "The Cockroach." Through the courtesy of the officers of the United States Department of Agriculture, blocks of many excellent figures from the publications of the Entomological Division of that office have been obtained. Permission to use two of these (figs. 70 and 149), which are copied from Curtis' "Farm Insects," has been kindly granted by Messrs Gurney and Jackson; while for four others (figs. 15, 31, 47 and 51) copied from Mr Cheshire's admirable work on the Bee, I am indebted to the courtesy of Mr L. Upcot Gill. I have also to thank the council of the Entomological Society, Mr J. T. Carrington, editor of *Science Gossip*, the publishers of *Natural Science*, and of the *Irish Naturalist*, Dr A. R. Grote, Mr R. I. Pocock and Mr R. Welch, for the use of various blocks. The source of every figure borrowed or copied is acknowledged in its description.

The selection of material has been a work of difficulty; and a truly judicious and even treatment of the subject would tax the powers of a veteran in the science. Yet the writing of this little book has been a pleasant task, and I shall be well repaid if it prove, in any degree, useful to my fellow-students of a delightful chapter in the great book of Nature.

GEO. H. CARPENTER.

DUBLIN, *May*, 1899.

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Chapter I

THE FORM OF INSECTS

To wonder at a thousand insect forms,
Whose shape would make them, had they bulk and size,
More hideous foes than fancy can devise,
With helmet-heads and dragon-scales adorned.—Cowper.

What is an Insect?—Adam, in the Book of Genesis, to whom every living creature was brought to be named, is a striking picture of the men of our day, learning to look with wondering interest on the myriads of animals that share with us this earth as a dwelling-place. Their vast numbers and the variety of their forms and habits seem at first to render their systematic study a hopeless task. But a general survey of the animal world teaches us that we can recognise several large groups, each marked off from the rest by some special plan of structure. The animals of one such group (to which we ourselves belong), with inner bony skeleton and two pairs of limbs, are distinguished as Back-boned (*Vertebrates*); those of another group—soft, boneless, and limbless creatures, like snails and oysters, often protected by a hard, limy shell, as Soft-bodied (*Molluscs*). Such great groups are often spoken of as the animal Sub-kingdoms. But most modern naturalists, regarding the living inhabitants of the earth to-day as the modified offspring of the vanished races of the past, and believing that between all creatures there is some relationship, distant or near, prefer to call each of

these main divisions a Branch or Clan (*Phylum*) knit together by the tie of a common ancestry.

There is a Branch which comprises animals formed of a number of segments placed one behind the other, covered at least in part with a hard outer skeleton, and feeding and moving by means of a number of pairs of jointed limbs, some of which are used as feelers, some as jaws, and others as legs. As members of this Branch we at once recognise bees, beetles and moths; centipedes and millipedes; scorpions, spiders and mites; crabs, lobsters and woodlice. By the older naturalists all these creatures were called *Insects*, the name being suggested by the division of the body into sections. But nowadays it is usual to apply the term *Arthropods* (jointed-legs) to the whole Branch, and to restrict the term *Insects* to one of the classes into which the Branch has been sub-divided. By *Insects*, then, modern naturalists understand *those Arthropods the segments of whose bodies are, in the adult state, grouped in three divisions:* (1) *a well-marked head bearing one pair of feelers and (normally) three pairs of jaws*; (2) *a fore-body (thorax) bearing three pairs of legs and (usually) two pairs of wings*; and (3) *a hind-body (abdomen) without legs.* Accepting this definition we consider a Bee, a Dragonfly or a Cockroach to be an insect; but not a Centipede, which, though possessed of a distinct head with feelers, has at least fifteen pairs of legs; nor an eight-legged Spider whose head, bearing no feelers, is not distinct from the fore-body; nor a Lobster, which also has the head fused with the fore-body, and possesses two pairs of feelers, six pairs of jaws and five pairs of legs, as well as a pair of limbs on each segment of the hind-body.

Having thus defined what is meant by an insect, we pass on to examine in some detail the form and structure of a typical member of the class. It is

convenient to take as our type a primitive kind of insect, one in which the various parts of the body are not very highly modified or specialised. Such an insect is provided for us in the common Cockroach of our kitchens (1). And as we examine its various organs, we can compare with them the corresponding organs in some higher insects, which have left the cockroach far behind in the advance towards perfection of structure.

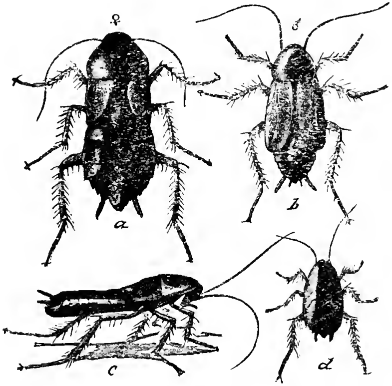


FIG. 1.—The Common Cockroach (*Blatta orientalis*). *a*. Female; *b*. Male; *c*. Female (side view); *d*. Young. Natural size. From Marlatt, Bull. 4 (n.s.) Div. Ent. Dept. Agric. U.S.A.

A short examination of a Cockroach (fig. 1) shows us that it presents the threefold division of the body mentioned above as characteristic of insects. There is a distinct head, joined to the fore-body by a narrow flexible neck, and bearing a pair of long feelers. The fore-body (thorax) consists of three segments, each of which carries a pair of legs, and each of the two

hinder ones in the male, also a pair of wings; in the female the wings are much reduced. The hind-body (abdomen) is made up of eleven segments (only eight of which are readily visible); it bears no walking legs, but the short, spindle-shaped appendages (cercopods) at the tail end must probably be regarded as modified limbs.

Cell-Structure.—Before considering in detail the various organs of the cockroach it is necessary to glance for a moment at the minute structure of insect tissues. Each visible part of any animal's body is built up by a vast number of tiny, microscopical living units known to the naturalist as *cells*, being either actually composed of a multitude of cells or formed (secreted) by their activity. The cell-substance is granular and semi-fluid, and its essentially living constituent is a highly complex chemical compound known as *protoplasm*. Within each cell a special portion of the contents, of a markedly granular nature, can be recognised as forming a small *nucleus*. There is every reason for believing that the nucleus is the seat of the cell's activity. In order to study the minute structure of cells, naturalists stain animal tissues with carmine and other dyes before examining them under the microscope. It is found that the nuclear substance takes up these stains more readily than the general cell-substance, so that the nucleus of a cell in a tissue prepared for microscopic study appears intensely coloured. High magnification shows, however, that a special material within the nucleus, arranged in the form of fine threads which are sometimes netted and sometimes looped, takes up the stains much more markedly than the rest of the nuclear substance. This deeply-staining material is known as *chromatin*, the rest of the nuclear substance as *achromatin*. Which of these two materials is especially the centre of

nuclear activity is still a disputed question among naturalists (56).

Chitin.—The outer skin of the cockroach is hard and firm, owing to the presence of a chemical substance known as *chitin*,[1] which is specially characteristic of arthropods. The chitinous skin, or exoskeleton, is composed of a number of thin layers which are secreted by the layer of active cells forming the under-skin (*hypodermis*) of the insect (fig. 2). The hard coat of an insect is built up of a number of distinct chitinous plates, each of which is known as a *sclerite*. Sometimes a number of sclerites are firmly joined together so as to form a rigid part of the skeleton —the head-capsule for example; the lines of junction between such sclerites are known as sutures. In other cases sclerites may be separated from each other by intervening tracts of soft membranous skin; this is necessarily the case where motion between the parts is required, as in the segments of the hind-body or of the legs.

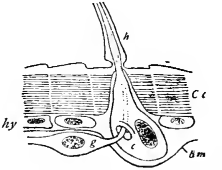


FIG. 2.—Section through Insect's skin *cc.* Chitinous layer; *c.* its generating cell; *g.* nerve-cell; *h.* hair; *hy.* hypodermis. From Miall & Denny's "Cockroach."

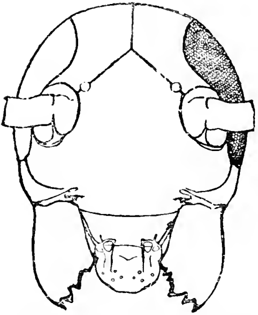


FIG. 3.—Head of Cockroach (*Blatta orientalis*), front view. Magnified 10 times. From Miall & Denny's "Cockroach."

Head.—The Cockroach's head is rounded above

[1] The chemical formula of chitin in $C_{15}H_{26}N_2O_{10}$.

and at the sides, somewhat flattened before and behind (figs. 3, 4). It is composed of several sclerites. In front the face (*clypeus*) is conspicuous; from its lower edge hangs the upper lip (*labrum*) behind which is the membranous roof (*epipharynx*) of the mouth, the seat of the sense of taste. Above the face, forming the top and back regions of the

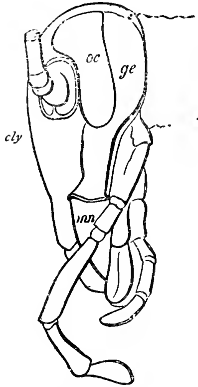


Fig. 4.—Side view of Cockroach's Head. *cly.* face; *oc.* eye; *ge.* cheek; *mn.* mandible. Magnified 10 times. From Miall & Denny.

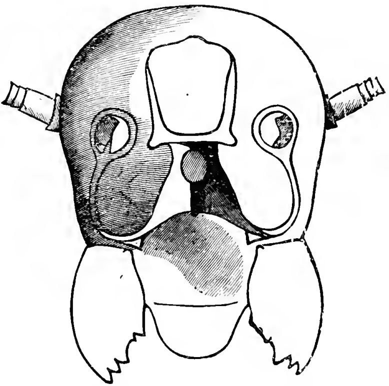


Fig. 5.—Fore-half of Cockroach's Head from behind, showing tentorium and mandibles. Magnified 12 times. From Miall & Denny.

head, is the crown (*epicranium*), consisting of two plates united by a central suture. At either side we find a large compound eye and a cheek (*gena*). Behind the head is a large shield-shaped opening (*occipital foramen*), through which the gullet, nerve-cords, and air-tubes pass back into the body. Within the head-capsule is a complex inner skeleton (*tentorium*) formed

by inpushing of the skin, which gives attachment to the muscles used in moving the head and jaws (fig. 5) (**1**).

These various parts of the head-skeleton vary greatly in different insects. The Cockroach's head, as we have seen, is elongated from above downwards, consequently the face and upper lip are largely developed. But in many Beetles the head is elongated from behind forwards, and in this case the epicranium and *gula* (a sclerite beneath the head, absent in the cockroach) are greatly extended, while the face is much reduced and the labrum is often absent. In the cockroach the eyes occupy relatively only a small portion of the head-surface. But in insects of rapid flight, these organs being of the greatest importance, become much enlarged; in Moths the eyes occupy nearly all the side regions of the head, while in some two-winged Flies and Dragon-flies they overspread the top of the head as well, touching each other along the middle line. The heads of such insects as these tend to become globular in form (fig. 10).

Except for a few bristles on the upper lip, the Cockroach's head is smooth and naked. But in very many insects the surface is ridged and furrowed, or pitted; while it is often clothed in the same way as the rest of the insect's body, with a dense hairy covering, as in Bees (fig. 15), or with the modified flattened hairs known as scales, as in Springtails and Moths.

The epipharynx (**2**), which in the Cockroach forms a lining to the roof of the mouth, is in the Bee (fig. 15 *g*) visible outside. It becomes greatly lengthened and chitinised in some Flies and Fleas, forming, with the upper lip, a formidable piercing-organ (fig. 8).

Appendages of the Head.—We have noticed that an insect's body is built up of a number of segments situated one behind the other. At first sight it might seem that the head must be regarded as the foremost

of these segments. But no single segment of the body carries more than one pair of limbs or appendages. In the cockroach's head we shall find four pairs of appendages. We are therefore led to conclude that in the head there are at least four segments fused together. And when development is taken into account it will be found that the number of segments in the insect head is certainly greater than this.

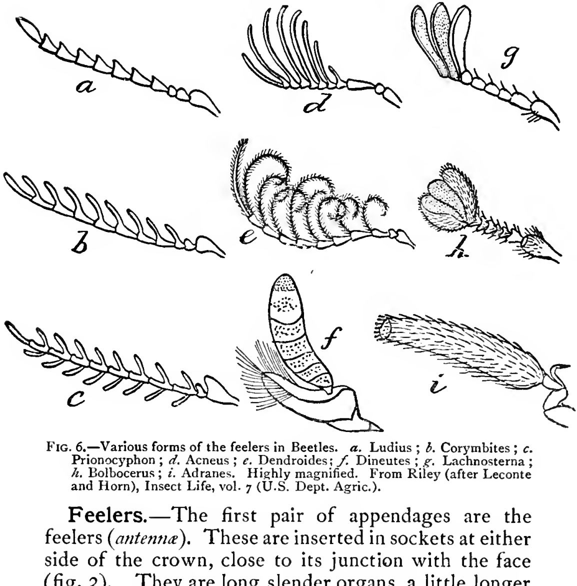


Fig. 6.—Various forms of the feelers in Beetles. *a.* Ludius; *b.* Corymbites; *c.* Prionocyphon; *d.* Acneus; *e.* Dendroides; *f.* Dineutes; *g.* Lachnosterna; *h.* Bolbocerus; *i.* Adranes. Highly magnified. From Riley (after Leconte and Horn), Insect Life, vol. 7 (U.S. Dept. Agric.).

Feelers.—The first pair of appendages are the feelers (*antennæ*). These are inserted in sockets at either side of the crown, close to its junction with the face (fig. 3). They are long slender organs, a little longer than the body in the male cockroach, not quite as long

as the body in the female (fig. 1). Each feeler is jointed, consisting of about eighty rings or segments, the first three of which are considerably larger than the rest. Each segment bears a number of minute stiff bristles.

The form of the feelers in different insects is exces-

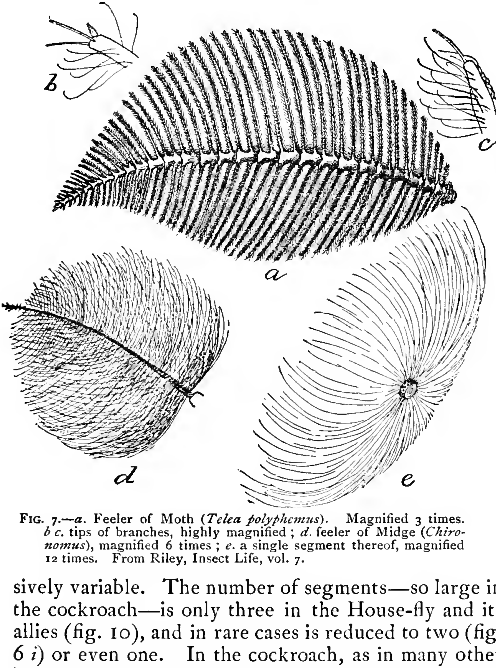


FIG. 7.—*a*. Feeler of Moth (*Telea polyphemus*). Magnified 3 times. *b c*. tips of branches, highly magnified ; *d*. feeler of Midge (*Chironomus*), magnified 6 times ; *e*. a single segment thereof, magnified 12 times. From Riley, Insect Life, vol. 7.

sively variable. The number of segments—so large in the cockroach—is only three in the House-fly and its allies (fig. 10), and in rare cases is reduced to two (fig. 6 *i*) or even one. In the cockroach, as in many other insects, the feelers taper to a point, but in Sawflies,

Butterflies, and some Beetles they are thickened into a club at the tip (fig. 6 *h*).

In many insects the feelers are divided into a basal part (*scape*) and a distal part (*flagellum*), marked off from each other by a sharp angle (fig. 15). In the Chafers and Stag-beetles the terminal segments are extended at one side to form plate-like processes; such feelers are defined as *lamellate* (fig. 6 *g*).

In many insects the segments bear processes or branches, then the feelers become saw-shaped (*serrate*) (fig. 6 *a*), or comb-shaped (*pectinate*) (fig. 6 *b*, *c*, *d*). When the segments of the feelers (fig. 7 *d*, *e*) or their processes (fig. 6 *e*, 7 *a*, *b*, *c*) carry numerous long hairs, they are said to be feathered. The feelers are of the greatest importance to the insect as organs of touch; and the hairs which they carry, in conjunction with the nerve-endings within the segments, to be described later, serve as organs of smell and hearing. The feelers of the male insect are often more complex than those of the female (figs. 8, 9).

Mandibles.—The other three pairs of appendages of the insect head are connected with the mouth, and serve for biting, piercing, or sucking food. The first pair are the *mandibles*. In the Cockroach these are strong biting jaws, evenly rounded on the outer and toothed on the inner edge. The outer basal corner (*condyle*) of the mandible articulates with the lower part of the epicranial plate, the inner basal corner (*ginglymus*) with the face (fig. 3). By means of powerful muscles attached within the head-skeleton, these mandibles can be opened and shut transversely across the mouth. When closed the teeth of the two jaws interlock, and the devastating effect of their action on food-stuffs and wearing apparel is too well known to most housekeepers.

Biting mandibles, like those of the cockroach, are found in a very large number of insects—Grass-

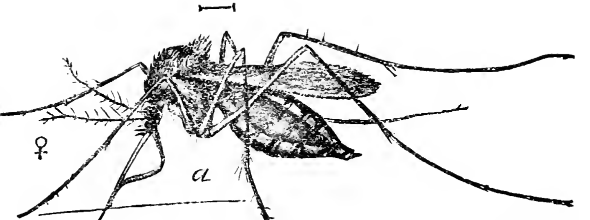


FIG. 8.—Female Gnat (*Culex pungens*) using her piercing labrum-epipharynx. Magnified 7 times.

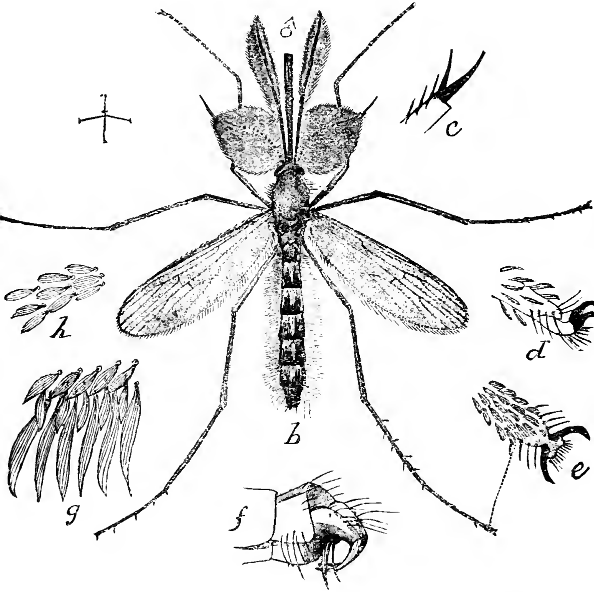


FIG. 9.—Male Gnat (*Culex pungens*). *b*, magnified 7 times; *c. d. e.* tips of fore, middle, and hind-foot, the last with pad; *f.* hinder end of abdomen, from side, with claspers, magnified; *g.* scales from wing-edge; *h.* scales from wing-disc, highly magnified. From Howard, Bull. 4 (n.s.) Div. Ent. U.S. Dept. Agr.

hoppers, Sawflies (fig. 11 *C*, *D*), and Beetles for example. In those beetles which live by prey the teeth of the mandibles are prominent and sharp, overlapping when the jaws are closed. Some male insects have the mandibles much more strongly developed than have the females. This is the case in the Stag-beetles, in many exotic Longhorn-beetles, and in the gigantic American Lacewing-flies (*Corydalis*). The mandibles of Wasps are very like those of cockroaches or beetles, but in Bees these jaws are small and club-shaped, being used for kneading wax as well as for biting (fig. 15 *m*).

Many insects have the mandibles developed not as biting jaws, but as lancets for piercing animal or vegetable substances from which food can be sucked. Such are the mandibles of Bugs, Cicads (fig. 14 ii *a*, *b*, *c*) and Plantlice, as well as of some two-winged flies—Gadflies and Gnats for example. Mandibles when modified as piercers do not move transversely across the mouth, but are pushed directly outwards, and drawn backwards when not in use.[1] It is of great interest to notice that in some of the most primitive of insects, the Springtails, the mandibles are withdrawn into the head-capsule and are capable of both transverse and vertical motion, thus affording a link between biting and piercing jaws (98).

Some insects which feed by suction without the necessity of piercing, or take no food at all in the adult stage, have the mandibles in a very reduced (vestigial) condition, or altogether wanting. May-flies, Caddis-flies, Moths (fig. 13 *m*), and many two-winged Flies are examples of such insects.

Maxillæ (First Pair).—The mandible of an insect differs from most of the other appendages in being formed only of a single sclerite. In a few beetles,

[1] But these piercers are thought by some students (4, 8) to belong to the first maxillæ.

however, sutures have been observed on the mandible, suggesting that it is really built up of several distinct parts, like each jaw of the pair which follows next behind. These jaws are the *first pair of maxillæ*; and, in consequence of the modification of the second pair, they are often called simply "the maxillæ." In the Cockroach (fig. 12) they are of typical form, made up of a basal, horizontal segment (*cardo*) to which is jointed a stout vertical segment (*stipes*). The latter bears at its end a five-segmented *palp* (which may be regarded as a shortened leg), an outer lobe or hood

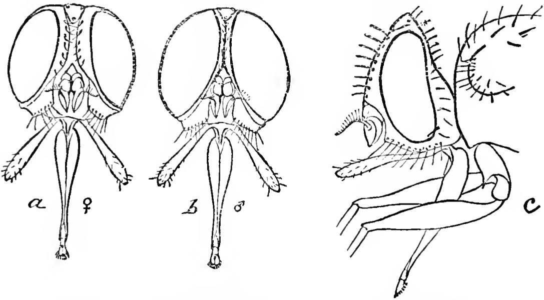


FIG. 10.—Head of Fly (*Hæmatobia serrata*). *a*. Female, front view; *b*. male, front view; *c*. side view. Magnfied 25 times. From Riley, Insect Life, vol. 2 (U.S. Dept. Agr.).

(*galea*) in front and an inner lobe or blade (*lacinia*) behind. The blades serve, in conjunction with the mandibles, to masticate the food, while the palps are used as organs of touch, exploring the surface over which the insect walks.

Many insects possess maxillæ like those of the cockroach—Sawflies (fig. 11 *E*) and Beetles for example, though the number of segments in the palp is often reduced.

In Dragonflies corresponding parts are to be found, but the palp is composed of a single segment only. In Caddis-flies, the palp and hood are well developed, but the blade is wanting. In Moths and Butterflies each hood is long, flexible and grooved; it can be coupled with its fellow to form the tube through which those insects suck honey or other liquid food. This tube can be stretched out or rolled up in a spiral beneath the insect's head. The palps are rarely developed, the blade almost always absent (fig. 13). In Bees, on the other hand, the blade is long and broad, forming a flexible piercer (fig. 15 *mx*), there is no hood, and the palp (fig. 15 *mxp*) is much reduced. In Bugs, Cicads (fig. 14 iii *a*, *b*, *c*) Plantlice, and many Flies the maxillæ, like the mandibles, are needle-like piercers, the piercing organ probably representing the blade of the maxilla. The palp is absent in bugs and their allies, but is sometimes present in flies (**1**, **2**).

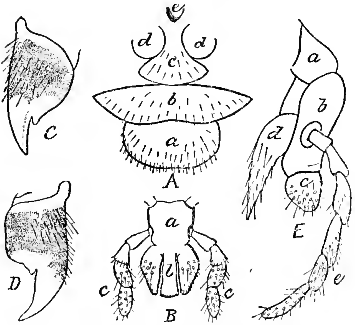


FIG. 11.—Part of Head with jaws of Sawfly (*Pachynematus*). *A*. Front of head; *a*. labrum; *b*. clypeus; *c*. epicranium, with (*d.d.*) antennal cavities. *C.D.* Mandibles. *E*. 1st maxilla; *a*. cardo; *b*. stipes; *c*. galea; *d*. lacinia; *e*. palp. *B*. Fused 2nd maxillæ; *a*. mentum; *b*. ligula; *c*. palp. Magnified. From Marlatt, Bull. 3 (tech. ser.), Div. Ent. U.S. Dept. Agr.

Maxillæ (Second Pair).—The third pair of jaws in the Cockroach are made up of similar parts to those

found in the second pair, though these parts are smaller and simpler. The basal segments (*cardines*) are fused together, forming a broad plate or flap (*submentum*) (fig. 12 *sm*) which hangs below the back region of the head, behind the mouth. To this the stipites are attached, their bases joined together to form a smaller plate (*mentum*) (fig. 12 *m*) and their separated distal portions each carrying its hood (fig. 12 *pg*) and blade. The three segmented palp (fig. 12 *pa*) is borne on a process (*palpiger*) situated outwardly at the base of the stipes. The pair of jaws thus made up is the *second pair of maxillæ*. But because of the fusion of the basal parts of these jaws to form an unpaired plate, and their position behind the mouth (or, in insects whose head is carried horizontally, below the mouth), most entomologists call them the lower lip (*labium*).[1]

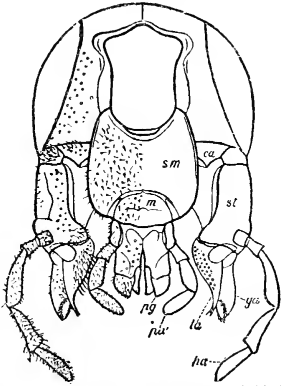


FIG. 12.—Cockroach's Head from behind showing maxillæ. Magnified 10 times. *ca.* cardo; *st.* stipes; *ga.* galea; *la.* lacinia; *pa.* palp, of 1st maxillæ; *sm.* submentum; *m.* mentum; *pg.* galea; *pa.* palp, of 2nd maxillæ. From Miall & Denny.

On the inner (front) side of this pair of jaws is situated a fold in the skin of the mouth known as the tongue (*lingua* or *hypopharynx*). On the hinder surface of the tongue opens the duct of the spittle-glands (1).

In the more highly developed insects, the fusion of

[1] The hoods (*galeæ*) of these jaws are often known as the *paraglossæ*.

the jaws of this pair is much more complete than in the cockroach, and their various parts are much harder to make out. In Beetles we find a broad basal plate, which, though known as the "mentum," probably represents the fused cardines and therefore really corresponds with the submentum of the cockroach. From this arises a tongue-shaped or pointed central piece, known as the *ligula*, formed by the union of the two stipites; side-lobes sometimes represent the hoods, and bristle-bearing tubercles the blades. The short segmented palps, borne on palpigers which spring from the base of the ligula, are the only clear indication that the "lower lip" of a beetle is really made up of a pair of jaws (fig. 16). The second maxillæ of a Saw-fly (fig. 11 *B*) are intermediate between those of a Cockroach and those of a Beetle, the fusion being less complete than in the latter insects.

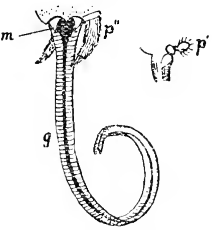


FIG. 13.—Jaws of Burnet Moth (*Zygæna*). *m.* mandible; *g.* galeæ of 1st maxillæ; *p'.* palp of do.; *p''.* palp of 2nd maxillæ. After Miall & Denny.

Still more highly modified are the second maxillæ in many insects which take food by suction. In the Bugs and Cicads these jaws unite to form a strong jointed sheath (fig. 14, iv *b*, *c*,) within which the piercing stylets move to and fro; the palps, very rarely present in a greatly reduced condition, are usually wanting. In two-winged Flies the second—or according to another view (4, 8) the first—maxillæ form a long proboscis, the expanded end of which (apparently made up of the united hoods) is a complex sucker; the palps are present (fig. 10), very long and

hairy in male Gnats (fig. 9 *b*). In Bees the united stipites of the second maxillæ form an elongate mentum which carries outwardly the pair of long hairy palps (fig. 15 *lp*), serving as organs of touch, and inwardly the short hoods (*galeæ*) (1, 2).

Tongue. — The hoods partially surround, as

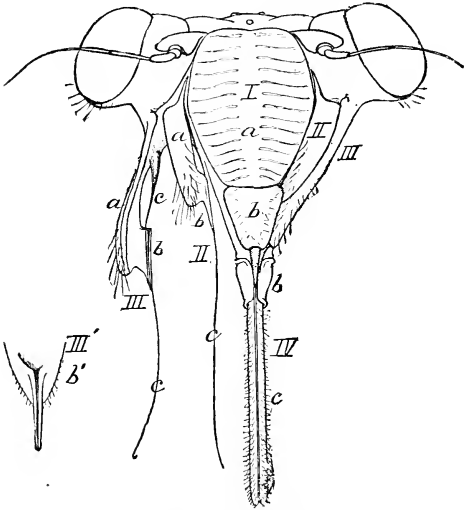


FIG. 14.—Cicad's Head, front view. I. *a*. clypeus, *b*. labrum. II. Mandibles. III. 1st maxillæ (*a*. base, *b*. sheath, *c*. piercer). III'. Inner view of sheath. IV. 2nd maxillæ forming beak (*b*. mentum, *c*. ligula). Magnified 8 times. From Marlatt, Bull. 14 (n.s.) Div. Ent. U.S. Dept. Agr.

sheaths, the long, flexible hairy tongue (fig. 15 *l*) of the Bee, which corresponds with the tongue (*hypopharnyx*) of the Cockroach. In the latter insect, as mentioned above, this organ is simply a fold of skin

within the base of the second maxillæ. In the bee it is a marvellous structure adapted for licking and

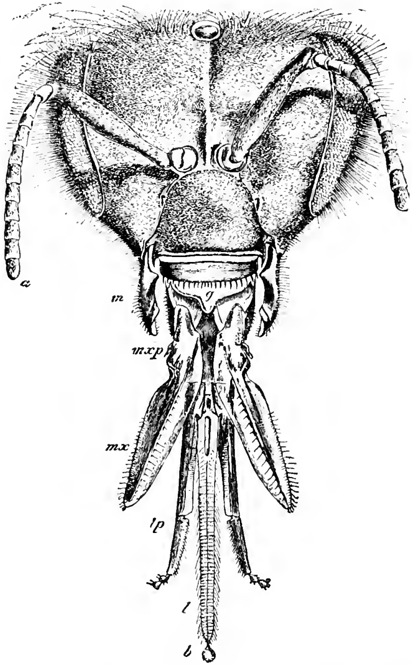


FIG. 15.—Head and jaws of Worker Bee. *a.* feelers; *m.* mandible; *mx.* 1st maxilla (blade); *mxp.* do. palp; *lp.* palp of 2nd maxilla; *l.* tongue; *b.* its "spoon"; *g.* epipharynx. Magnified 12 times. From Benton (after Cheshire) Bull. 1 (n.s.) Div. Ent. U.S. Dept. Agr.

sucking, folded lengthwise so as to form a central

and two side grooves (which, owing to the numerous fine hairs on their edges, are practically tubes) and furnished at the lip with a circular concave "spoon" (fig. 15 *b*) whose edges are beset with branched hairs for gathering honey from flowers. In some Flies the hypopharynx is put to a very different use, being transformed into a piercing stylet, which in the Gnats attains a very formidable size and in the Fleas is provided with saw-teeth on its edge (2).

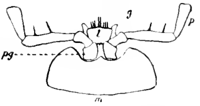


FIG. 16.—Second Maxillæ of Ground Beetle. *m.* "mentum"; *l.* ligula; *pg.* palpiger; *p.* palp; *g.* galea. Magnified.

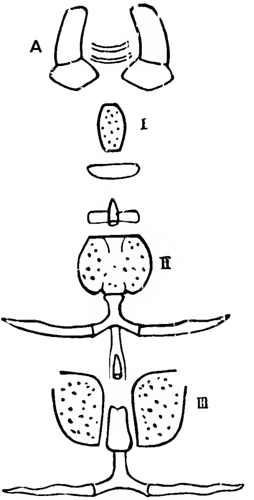


FIG. 17.—Ventral Sclerites of Neck (*A.*) and Thorax (I. II. III.) of Male Cockroach. Magnified 6 times. From Miall & Denny.

Neck.—Between the cockroach's head and forebody intervenes a slender flexible neck, which is strengthened by light chitinous plates (*cervical sclerites*). Two of these are situated on the upper surface; they are triangular and arranged side by side closely behind the head. On each side of the neck are two broad, quadrate sclerites, one behind the other, and beneath, two narrow transverse plates, also one behind the other (fig. 17 *A*). The fact that the base of the second maxillæ is connected with

these neck-plates gives support to the suggestion that they should be regarded as the hinder segment or segments of the head, which have not become fused with the head-capsule. There is no doubt that the greater part of the capsule is built up of

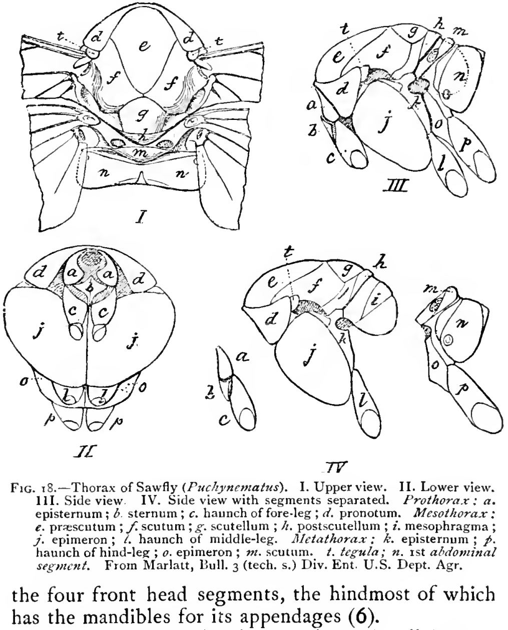


FIG. 18.—Thorax of Sawfly (*Puchynematus*). I. Upper view. II. Lower view. III. Side view. IV. Side view with segments separated. *Prothorax: a.* episternum; *b.* sternum; *c.* haunch of fore-leg; *d.* pronotum. *Mesothorax: e.* præscutum; *f.* scutum; *g.* scutellum; *h.* postscutellum; *i.* mesophragma; *j.* epimeron; *l.* haunch of middle-leg. *Metathorax: k.* episternum; *p.* haunch of hind-leg; *o.* epimeron; *m.* scutum. *t. tegula; n.* 1st *abdominal segment.* From Marlatt, Bull. 3 (tech. s.) Div. Ent. U.S. Dept. Agr.

the four front head segments, the hindmost of which has the mandibles for its appendages (6).

Fore-body.—In the Cockroach, as in all insects, the fore-body (thorax) consists of three segments,

known as *prothorax*, *mesothorax*, and *metathorax*. Each of these segments is regarded as made up of an upper sclerite—the *notum* or *tergum*, a lower one—the *sternum*, and a pair of side pieces—the *pleura*. In the cockroach, the *pronotum* is broad and rounded in front; the head can be drawn in beneath it. It is larger than the two succeeding tergites (*mesonotum* and *metanotum*) (see fig. 23). These are pale and thin in the male insect, being covered by the wings. In the female, which has the wings undeveloped, they are hard and brown like the other sclerites. The *prosternum* is narrower than the *mesosternum*, and the latter is smaller than the *metasternum*, these sclerites increasing in size from before backwards, like the legs which are associated with them. The mesosternum is divided into two halves in the female cockroach, as is the metasternum in both sexes. Between each sternum and the insertion of the leg is the pleural part of the segment—two narrow plates, an inner *episternum* and an outer *epimeron* (fig. 19). Behind each sternum is a small central sclerite, the two hinder ones carrying long paired processes (forks) for the attachment of muscles (fig. 17). There is a hollow conical sclerite, showing a pit outwardly and a tubular process pointing inwardly towards the body-cavity, in front of the mesosternum, and a similar one in front of the metasternum; these are *apodemes*, which, like the forks, serve for the attachment of muscles (1).

In many insects the tergal plates of the fore-body are far more complex than in the cockroach. In the mesonotum and metanotum, four distinct parts placed one behind the other can sometimes be observed; they are known as the *præscutum*, *scutum*, *scutellum*, and *postscutellum* (fig. 18). The scutellum of the mesothorax is a very conspicuous structure in many

Beetles and Bugs. Among insects which habitually walk, run, or swim, the prothorax is usually distinct from the other segments. It may project backwards over them, as in many Water-bugs, or over the hind-body as well as in certain small Grasshoppers. In many Beetles it is ornamented with strong curving spines. But in insects which are specially adapted for powerful flight, such as Dragonflies, Moths, or Flies, the prothorax is reduced and the segments of the fore-body become, to a great extent, fused together, so as to build up a firm capsule for the attachment of the strong wing-muscles. In Ants, Bees, and other insects related to them, not only are the three usual segments of the fore-body fused together, but the first segment of the hind-body (fig. 18 *n*) is also united with them; the fore-body of these insects is known as an *alitrunk*. The most extreme variation is to be observed in the outward shape of the fore-body in different groups of insects. Paired erectile plates (*patagia*) are borne on the prothorax in Moths, and small plates (*tegulæ*) at the base of the fore-wing on the mesothorax in Moths, Sawflies (fig. 18 *t*), Bees, and other insects (2).

Legs.—Each segment of the fore-body bears a pair of legs. In this restriction of the locomotive limbs to six, insects show the highest specialisation of all arthropods. In the Cockroach, the front, middle, and hind legs are closely similar to each other, the size of the limbs increasing from before backwards (fig. 19). Each has a large conical basal segment, the haunch (*coxa*), which, in the cockroach, is remarkably large, taking up much of the space occupied in other insects by the side region of the fore-body. Jointed with the haunch is a small evenly bent segment, the *trochanter*. Then follows the principal segment of the leg, the thigh (*femur*), elongate, and

flattened, somewhat tapering at either end. To this

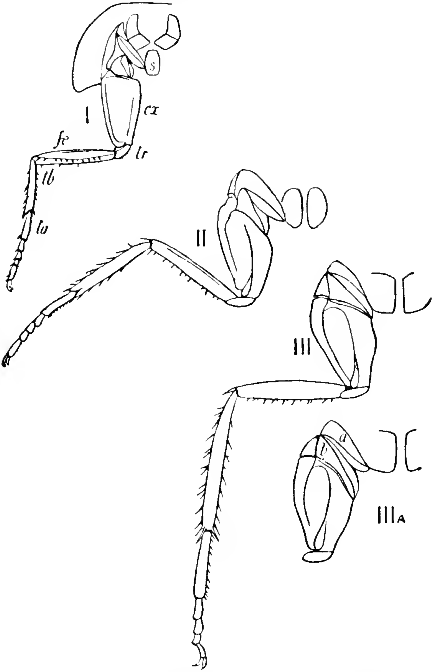


FIG. 19.—Legs and ventral thoracic sclerites of Female Cockroach. I. Fore-leg and prosternum (*s*); *cx.* haunch; *tr.* trochanter; *fe.* thigh; *tb.* shin; *ta.* foot. II. Middle-leg and mesosternum. III. Hind-leg and metasternum. IIIA. Shows the episternum (*a*) and epimeron (*b*) slightly separated. Magnified twice. After Miall & Denny.

succeeds the shin (*tibia*), more slender than the thigh,

and armed with formidable rows of strong spines. The end of the leg is formed by a five-segmented foot (*tarsus*), whereof the first segment is the longest, and the third and fourth the shortest; the fifth segment carries two claws (1).

The legs undergo the greatest modification according to their special functions in different insects (9, 10). The front pair, which are the shortest in the cockroach, are greatly lengthened in certain beetles which climb about on trees, and immensely widened in other beetles which burrow underground, while in the "pray-

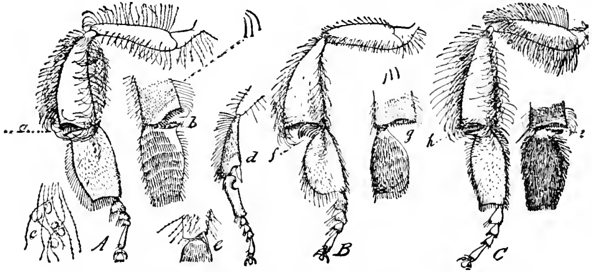


FIG. 20.—Modification in the legs of Bees. *A*. Honey-bee (*Apis*); *B. Melipona*; *C. Bombus*. *a.f.h.* outer view of hind-leg; *b.g.i.* inner view; *d.* fore-leg; *e.* tip of middle shin with spur; *c.* feathered hairs with pollen grains. From Riley, Insect Life, vol. 6 (U.S. Dept. Agr.).

ing-insects" and water-scorpions, they are modified into formidable pincer-like organs for seizing prey.

In many Beetles a cavity in the front shin lined with bristles serves as a "comb" for cleaning the feelers, which can be drawn through it. In Bees a still more perfect organ for the same purpose is formed by a semi-circular nick near the upper end of the first tarsal segment (164). The cavity is lined with thickened hairs, and its open edge can be bounded

by a hinged spine which hangs from the lower edge of the shin (fig. 20 *d*). Water-insects generally have the front legs much shorter than the other two pairs. In certain Butterflies the front pair are so greatly reduced as to be quite useless for walking, so that these insects have practically only four legs. The legs of the middle pair undergo, as a rule, less modification than those of the front and hind pairs, but in some Water-bugs they are the longest and strongest of all the legs. In other water-bugs and in Water-beetles both the middle and hind pairs are flattened and tapering, serving to propel the insect through the water after the manner of oars. The hind legs are generally the longest of all; in the Grasshoppers and Locusts they are excessively long and powerful, enabling the insects to spring high into the air. The hind-legs of Bees are specially modified for the collection and carrying of pollen, by the broadening of the shin and the first tarsal segment. The feathered hairs (fig. 20 *c*) on the body entangle pollen grains which are brushed out by the rows of hairs on the inner face of the wide tarsal segment (fig. 20 *b*, *g*). The pollen is then combed out by the bristles (fig. 20 *a*) on the hind edge of the shin, and stored in the "basket" formed by the hollow on the outer face of the shin in conjunction with the curved hairs on its front margin. The broad sharp edges at the junction of shin and foot (fig. 20 *a*, *h*) serve as pincers for cutting wax. In Gnats (fig. 9) and Crane-flies all the legs are long and slender as compared with the body, while in some degenerate female insects they are greatly reduced and very feeble; in extreme cases of degeneration, the female bee-parasites for example, they are altogether wanting.

Many insects which walk with their tarsal seg-

ments flat on the ground have the under-surface of these segments broadened to afford support, and provided with special cushion-like thickenings of the skin or beset with glandular hairs secreting an adhesive fluid. Such hairs are specially present on the pad (*pulvillus*) which is to be seen between the bases of the claws in most insects. This pad has been regarded as a sixth segment to the foot (fig. 9 *e*). In flies and bees it forms a delicate membrane which, owing to the presence of the adhesive hairs, sticks closely to a smooth surface; it is by the action of these foot-pads, for example, that a fly is able to walk up a window-pane. But when the insect is passing over a rough object, the pad can be raised so as to escape injury, the claws then affording a secure foothold (**2**, **10**).

Careful observation and photography have shown that an insect, in walking or running, moves its legs in two sets of three, so that at each step it is supported on a tripod, formed of the first and third legs of one side with the second of the other. One tripod thus affords a firm base of support while the other three legs are being moved forward to their new position (**11**, **12**).

Wings.—A pair of wings is carried on the second segment (mesothorax) and another on the third segment (metathorax) of the fore-body. The narrow attachment of a wing to its thoracic segment is called its *base*, the outer margin (when the wing is unspread) is the *costa*, the inner margin the *dorsum*, and the hinder margin the *termen*. The angle between costa and termen is the *apex*; that between dorsum and termen the *anal angle* or *tornus*. In the male Cockroach, whose wings are well developed, the front pair are in texture firm and brown, in shape narrow oblong with rounded corners, while the hind pair are delicate

and hyaline, stiffened only along the front or outer edge (*costa*); shorter and much broader than the fore-wings (fig. 21). In all the wings a set of radiating and cross nervures can be observed. The arrangement of these nervures varies greatly in the different groups of insects. In the Cockroach's hind-wing, five principal radiating or longitudinal nervures can be distinguished; these are the *sub-costal*, *radial*, *ulnar*, *median*, and *anal*; in the fore-wing the ulnar is fused with the radial (fig. 21). In a Fly's wing (fig. 22) there are two sub-costals, a radial, an ulnar, two medians, and an anal. In the wings of Moths and other insects there are *cubital* nervures between the medians and the anals. But it is not at all certain that the nervures which have received the same names in different insects really correspond (13, 14).

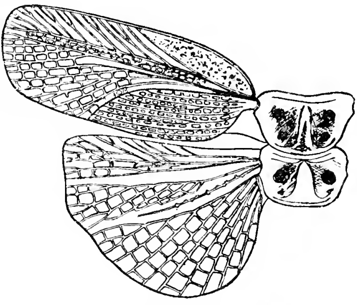


FIG. 21.—Mesonotum and metanotum of Male Cockroach with wings of left side. Twice natural size. After Miall & Denny.

Microscopic examination shows that an insect wing consists of a twofold layer of skin, the two layers being in contact except where they are thickened and raised into folds so as to form the firm tubular nervures, which serve as a supporting framework to the wing membrane, enclose air-tubes and serve as blood-channels (15).

The firm fore-wings of Cockroaches serve as covers beneath which the delicate hind-wings can be folded after the manner of a fan, and protected when not in use (fig. 22). In this respect the cockroach is more highly specialised than many other insects, which have all four wings of thin texture. In Dragonflies the two pairs of wings are closely alike in size and form. Often the front-wings are both larger and broader than the hind-wings, as in the Mayflies, Bees, Wasps, and their small relations, the extreme stage

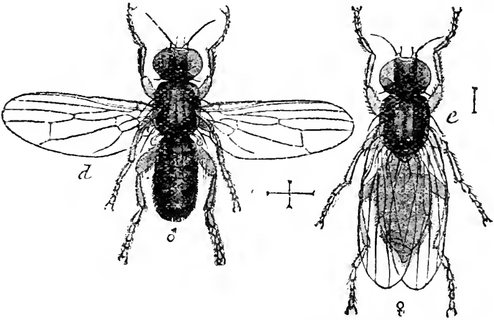


FIG. 22.—Cheese-fly (*Piophila casei*). *d.* Male; *e.* female with wings folded. Magnified 8 times. From Howard, Bull. 4 (n.s.) Div. Ent. U.S. Dept. Agr.

being reached in the Flies (fig. 22), whose hind-wings are reduced to small stalked knobs. Or the fore-wings are longer than the hind-wings, but also narrower, as in Stoneflies, Caddis-flies, and many Moths. In this latter case there is a tendency for the fore-wings to become of firmer texture than the hind-wings, and for the latter to be folded beneath the former when at rest. Thus the marked distinction between the two pairs which we notice in the Cockroach is reached,

and by a further development along the same lines, the fore-wings become so hard and horny that they can hardly be considered as "wings" at all, their function being simply to act as protecting sheaths for the hind-wings, which alone are used for flight, as in Beetles (fig. 69) and Earwigs. The wings of many insects are fringed or covered with hairs or bristles; those of Butterflies and Moths, Gnats, and other insects are clothed wholly or in part with flattened scales (fig. 9 *g*. *h*.).

In the female Cockroach the fore-wings are small, movable plates, reaching back only to the middle of the third segment of the fore-body; the hind-wings are represented only by a network on each outer corner of the metanotum. Organs thus reduced are said to be vestigial, and this is the condition of the wings in many female insects whose males have them well developed. In the American and German (fig. 94) cockroaches, not distant relations of our common kind, the wings of both sexes are, however, nearly similar. The presence of wings in the female of the common cockroach, in a reduced or vestigial condition, suggests that its ancestors had females winged like the males, a view confirmed by the presence of well-developed wings in the females of the allied kinds. And the vast majority of wingless insects are believed to be the descendants of winged ancestors. In many aquatic insects a tendency towards loss of wings can be observed. Certain water-bugs, for example, are habitually wingless, but the occasional presence of a winged specimen shows that the whole race has not yet lost the organs of flight. The small and humble insects known as Springtails and Bristletails are all wingless; as none of them have even traces of wings, and they are not nearly related to other insects, it is believed that the

ancestors of these groups never possessed the power of flying.

Hind-body.—The hind-body (abdomen) of an insect contrasts strongly with the fore-body. Its segments are, as a rule, closely similar to each other, and, in the adult, never bear legs. Very rarely, as in some Bristletails, do all the segments carry small pairs of limbs. Each segment is protected by an upper sclerite (*tergum*) and a lower one (*sternum*); the side regions (*pleura*) generally remain soft and membranous. In the male Cockroach ten segments

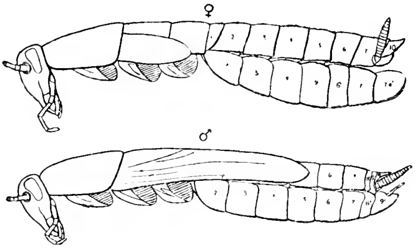


FIG. 23.—Outline of Male (♂) and Female (♀) Cockroaches from the side, showing abdominal segments (numbered 1-10). Magnified 4 times. After Miall & Denny.

are visible above, but the last three are very small; in the female only eight can be seen; these are the first seven and the tenth, with which the eleventh is fused, the eighth and ninth being hidden under the seventh (fig. 23). Viewed from beneath, nine sternites can be seen in the male and seven in the female, the eighth and ninth in the latter sex being withdrawn into the seventh. In more highly developed insects, the number of abdominal segments is smaller than in the cockroach, the three or four hind-

most being often retracted and concealed, or absent. In both sexes of the cockroach the first sternite is very much reduced, and the second is cut into on either side in front, on account of the backward direction of the hind legs. In the male the sternites from the third to the seventh are alike four-sided, broad and short; the eighth is much shorter, while the ninth is rounded behind. In the female, the third, fourth, fifth and sixth segments are similar, while the seventh is very large and ends in a blunt point, its hinder region being split lengthwise to allow the expulsion of the egg-capsule. The ninth segment in the male bears a pair of small simple limbs (*stylets*), while the eleventh, in both sexes, carries a pair of spindle-shaped limbs of sixteen segments (*cercopods*). In some insects—such as Bristletails, Stone-flies and Crickets—the cercopods are long and composed of numerous segments; in the Dragonflies they are hard, leaf-shaped plates. Occasionally the appendages of the eighth, ninth, or tenth segment form cercopods. The modification of the hinder segments in both sexes is specially concerned with the breeding function, and we shall give further attention to these segments and to certain parts of the skeleton connected with them when we consider the reproductive organs. Surrounding the vent (*anus*) are the small sclerites of the twelfth abdominal segment, the tergum and sternum being each divided into two lateral plates (**1, 59a**).

Nerves.—Insects, like most other animals, receive sensations from the outside world, and control the movements of the various parts of their bodies by means of a system of nerve-centres and cords, which get impressions from the sense-organs and stimulate or restrain the muscles. Nervous tissue, examined microscopically, is found to be made up of nerve-cells

(which have large nuclei and are often branched) and nerve-fibres connected with the cells. A nerve-centre (*ganglion*) contains both cells and fibres, the former mostly occurring in the outer parts of the mass, the latter lying more deeply; a nerve-cord, joining two nerve-centres, consists almost entirely of fibres. Both centres and cords are covered, and protected by a hard sheath (*neurilemma*) formed of cells with elongate nuclei (fig. 24) (**1**).

In the Cockroach we find in the head, in front of the gullet, a large nerve-centre, the brain (*supra-*

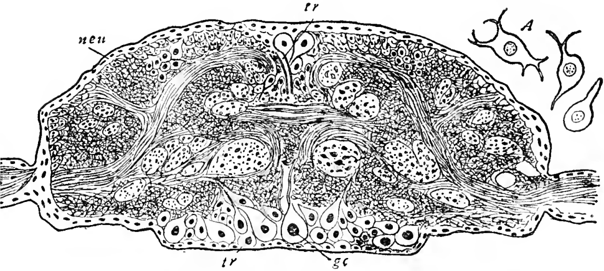


FIG. 24.—Cross-section of third thoracic ganglion of Cockroach. *tr.* air-tubes; *neu.* neurilemma; *gc.* nerve-cells. Magnified 70 times. *A.* nerve-cells more highly magnified. From Miall & Denny.

œsophageal ganglion), which gives off nerves to the eyes and feelers. The brain is connected by a thick nerve-ring with another nerve-centre (*sub-œsophageal ganglion*) giving off nerves to the jaws, and situated behind the gullet (fig. 25). From this passes backwards a pair of nerve-cords which run side by side to the hinder end of the body, connecting a series of nine nerve-centres, one in each of the three segments of the fore-body, and one in each of the first six segments of the hind-body

(fig. 36). The hindmost of these is larger than the rest and is regarded as formed of the fused nerve-centres of the last six segments. For a nerve-centre to each segment is the typical arrangement in arthropods.

Fusion of the nerve-centres of several segments, which in the Cockroach has taken place to the comparatively slight extent just mentioned, is carried much farther in more highly developed insects. In the Stag-beetles the three nerve-centres of the fore-body are distinct though the second and third are nearly united, but the number of nerve-centres in the hind-body is reduced to three. In Bees there are only two nerve-centres in the thorax and five in the hind-body (fig. 47 *ggg*). In Gadflies the three thoracic nerve-centres are fused into a single mass; those of the abdominal chain, though still distinct, are moved close together and far forward. In Chafers and in House-flies and their allies all the nerve-centres behind the sub-

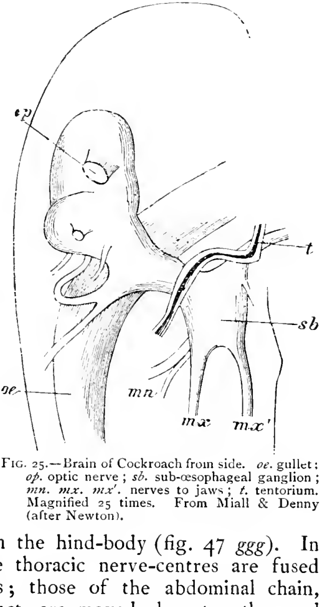


FIG. 25.—Brain of Cockroach from side. *oe.* gullet; *op.* optic nerve; *sb.* sub-œsophageal ganglion; *mn. mx. mx'.* nerves to jaws; *t.* tentorium. Magnified 25 times. From Miall & Denny (after Newton).

œsophageal ganglion are united into a single mass situated in the fore-body (2, 4). Such fusion of nerve-centres may be said to result in concentration of individuality; for where a nerve-centre is present in each segment, each segment is to some extent capable of independent life.

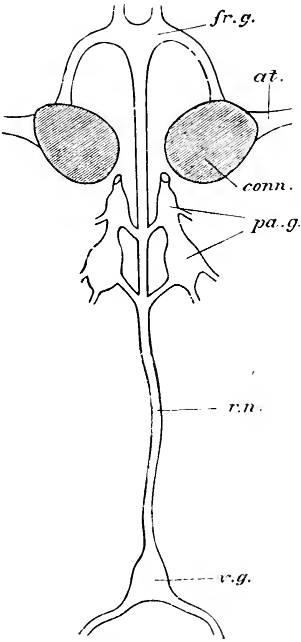


FIG. 26.—Stomato-gastric-nerves of Cockroach. *fr.g.* frontal ganglion; *at.* nerve to feeler; *conn.* connective; *pa.g.* paired ganglia; *r.n.* recurrent nerve; *v.g.* ventricular ganglion. Magnified. From Miall & Denny.

In addition to the nerves and nerve masses of the central chain, there is in insects a set of nerves associated with the front part of the food-canal. In the Cockroach a pair of nerves pass forwards from the nerve-ring around the gullet, above which they unite in a three-cornered nerve-centre (*frontal ganglion*). Thence a pair of small nerves run downwards to the upper lip, while a central (*recurrent*) nerve passes backwards along the gullet to a triangular nerve-centre

(*ventricular ganglion*) which lies on the crop, and gives off branched nerves to that organ and to the gizzard. On either side of the recurrent nerve, just behind the brain, are two nerve centres (*paired ganglia*), one behind the other. They are connected together by cords, also with the recurrent nerve, and with the brain; they give off nerves to the spittle-glands (fig. 26) (1).

Brain.—It has been mentioned that in the nerve-centres we find, generally speaking, bundles of fibres surrounded by layers of nerve-cells. In the brain the arrangement of the various parts is highly complicated. The brain of an insect is regarded as made up by the fusion of three pairs of nerve-centres. The foremost of these comprises by far the larger portion of the brain. Within the cellular envelope of the Cockroach's brain can be distinguished, on either side, a basal mass of fibres (*trabecula*) whence arise two

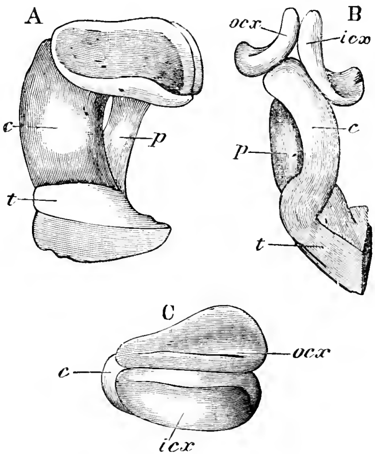


FIG. 27.—Lobes of Cockroach's brain. *A*. Inner view; *B*. front view; *C*. side view. *c*. cauliculus; *p*. peduncle; *t*. trabecula; *ocx*. outer and *icx*. inner brain-cap. From Miall & Denny (after Newton).

fibrous columns, the larger of which (*cauliculus*) is situated in front of the smaller (*peduncle*). On this latter rest two elongate, trough-shaped, cellular masses, the brain-cups (*calyces* or *gyri cerebrales*); the cellular envelope over these bodies is made up of smaller cells than those which form the envelope around the other parts of the brain; each stalk with its cup and cellular cover forms a "mushroom body" (fig. 27). From the upper central region arises, on either side, the large optic trunk which swells into an inner and an outer lobe of nerve-fibres connected with the eye. The outer lobe (fig. 30 *e. op*) contains a series of rod-like fibres arranged radially. All these parts—central masses, mushroom bodies, and optic trunks and lobes make up the fore-brain (*protocerebron*). The optic lobes are most highly developed in such insects as dragonflies, whose eyes are greatly enlarged. Development of the mushroom bodies is thought to correspond with increase of intelligence (**19**).

The mid-brain (*deutocerebron*) consists of paired-swellings, the olfactory or smelling nerve-centres, whence proceed the nerves to the feelers. The hind-brain (*tritocerebron*) comprises only that region of the nerve-ring around the gullet whence arise the nerves to the upper lip and food-canal described above (**2**, **17**, **18**).

Eyes.—We have next to consider the organs of special sense—sight, hearing, smell, taste, touch—by means of which an insect gets its knowledge of the outside world. The eyes are among the most beautiful and wonderful of all insect-structures. In the Cockroach the eyes occupy externally an elongate space with rounded ends, broader above, narrower below, on either side of the head (fig. 4 *oc.*). The transparent skin of this region is called the *cornea*. Examination of the surface of the cornea with a

microscope shows us that it presents the appearance of a honeycomb, being divided into a vast number of small six-sided figures (fig. 28 *a*), each of these is a *corneal facet;* there are about 1800 of them in the eye of the cockroach. In many insects, whose eyes are globular in form and much larger relatively to the size of the head than those of the cockroach, the number of corneal facets is greatly increased; some Dragonflies have 20,000 and some Hawk-moths as many as 27,000. On the other hand, the number of facets is sometimes very small; the eye of the well-known little Springtail, the "silver-fish" insect, has only twelve. In some water-insects the facets are relatively small in number and large in size, being also circular in shape instead of hexagonal (fig. 28 *b*). Eyes like this containing a number of corneal facets are known as *compound eyes* (**20, 21**). The compound eyes of male insects are often larger relatively than those of their females (fig. 31).

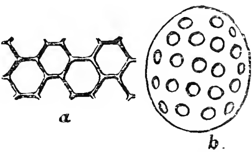


FIG. 28.—*a.* Hexagonal corneal facets from the eye of a Fly (*Empis*). Magnified 400 times. *b.* Eye of female Midge (*Clunio*) with few circular facets.

By cutting sections vertically through the eye, we are able to trace the connection between the facets and the nerve-fibres of the optic lobe of the brain. Each facet is seen to be composed of two transparent layers—an outer layer convex on both surfaces, and an inner layer concave outwardly and convex inwardly. With its base on this inner surface rests a short blunt crystalline cone surrounded by pigment; the apex of the cone is supported by a nerve-rod (*rhabdom*). The rod when cut across

is seen to be made up of four sections (*rhabdomeres*) arranged lengthwise. These are closely applied together for the greater part of the length of the rod, but at its outer end they are separated from one another, forming a kind of fork within which

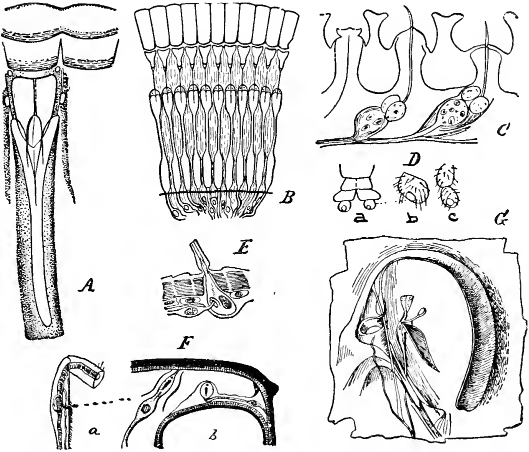


FIG. 29.—*A*. Single element (rod, cone and corneal facets) of Cockroach's eye (after Grenacher). *B*. Section through compound eye (after Miall & Denny). *C*. Organs of smell in Cockchafer (after Kraepelin). *D*. *a*. *b*. Sensory pits on cercopods of Golden-eye fly ; *c*. sensory pit on palp of Stone-fly (after Parkard). *E*. Sensory hair (after Miall & Denny). *F*. Ear of long-horned Grasshopper ; *a*. front shin showing outer opening and air-tube ; *b*. section (after Graber) (see also fig. 34). *G*. Ear of Locust from within (after Graber). All highly magnified. From Riley, Insect Life, vol. 7 (U.S. Dept. Agr.).

the tip of the cone rests (fig. 29 *A*). The rod is surrounded by elongate nerve-cells, each cell (*retinula*) corresponding with a rhabdomere. These cells contain much dark pigment, and are in connection with

the tiny nerve-fibres which pass through a finely-perforated membrane situated at the base of the rods (fig. 29 *B*). They are believed to form part of the *retina* of the eye—that portion which receives the impressions conveyed through the transparent facets, cones and rods.

A crystalline cone of the cockroach's eye, though a simple transparent body, is known to be formed out of four primitive "cone-cells." In Earwigs, Bugs, Craneflies, Midges and some Beetles, these four cells retain their original condition; no crystalline cone is formed, and the eyes of such insects are known as *acone eyes*. In the eyes of most two-winged Flies, the four cells are for the most part filled with a transparent fluid, but do not become fused together to form a true cone; such eyes are called *pseudocone*. Other insects have *eucone* eyes, in which, as in the cockroach, the cones are perfectly developed though they vary much in form (**2**, **20**).

It has been mentioned that the optic tract of the brain of the cockroach consists of two swellings, an inner (*opticon*) and an outer (*epiopticon*) on either side. Many naturalists consider that these swellings belong to the retina of the eye rather than to the brain. Absent in the cockroach, but present in the vast majority of insects, between the epiopticon with which it is connected by nerve fibres crossing each other (decussating), and the membrane at the base of the rods, is a third swelling. This is called the *periopticon*, and is, without doubt, a retinal structure. It consists of a series of rod-like pigmented nerve-cells, surrounded by small "chaplet cells" with large nuclei, and connected with the exceedingly fine nerve-fibres which pass outward through the perforated membrane to the retinulæ surrounding the eye-rods (fig. 30) (**20**).

The large conspicuous eyes of all adult insects are compound eyes, such as have been described, and no other kind of eye is present in the Cockroach. But very many insects are provided with simple eyes in addition to the compound eyes. Examining the top of a Bee's head, for instance, we notice three simple eyes (*ocelli*) (fig. 31). The skin over such a simple eye is transparent and swollen, forming a doubly convex lens; beneath this a cup-shaped mass of elongate pigmented cells form a retina, each cell

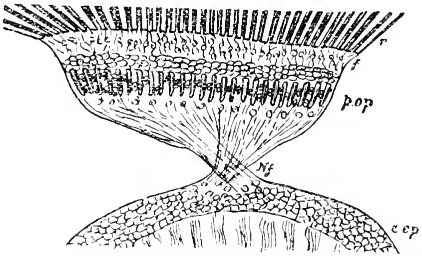


FIG. 30.—Section of part of optic tract of Blowfly. *r.* rhabdoms ; *f.* fine branching nerve-fibrils ; *p. op.* periopticon ; *Nf.* decussating nerve-fibres ; *c op.* epiopticon with outer cellular layer and inner, radially arrayed nerve-fibres. Highly magnified. After Hickson, Quart. Journ. Mic. Sci. vol. 25 (n.s.).

ending above in a transparent rod directed toward the lens and being connected below with a nerve-fibril (fig. 32). The nerves in connection with these simple eyes come off from the front upper region of the fore-brain, independently of the nerve tracts which supply the compound eyes.

Few questions in natural history have given rise to more discussion than the nature of insect vision. It is generally believed that the lens of a simple eye forms an inverted image of an outside object, which is perceived, as in our own eyes, by means of the

retinal cells. There can be little doubt, however, that these simple eyes can only see objects a few inches away, and that the sight is much less clear than that of the eyes of back-boned animals. With regard to the compound eyes, it is supposed that each set of facet, cone, and rod lets an exceedingly fine pencil of light pass through, the surrounding dark pigment absorbing all the oblique rays. Consequently each element of a compound eye perceives only a very small part of the field of vision, and the insect's view of the outside world is made up of a vast number of

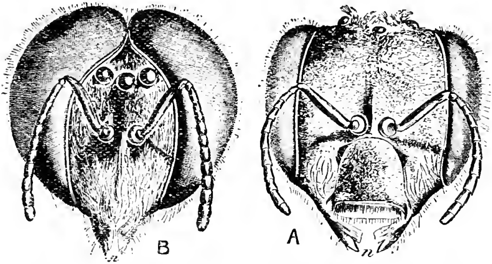


FIG. 31.—Heads of Male (*B*) and Female (*A*) Honey-Bees, showing compound and single eyes. Magnified 10 times. From Benton (after Cheshire), Bull. 1 (n.s.) Div. Ent. U.S. Dept. Agr.

small visual pictures. The supposed similarity of such a view to the effect on our own sight of mosaic work has led to the application of the term "mosaic" to the vision of the compound eyes of insects. It is evident that the extent of an insect's field of view must depend on the number of facets in its compound eyes and the approximation of the eyes to a globular form, while the distinctness of the sight increases as the size of the individual facets grows less. But the widest difference of opinion prevails as to the perfec-

tion of insect sight. Some naturalists suppose, from the accuracy and rapidity of an insect's flight, that its sight must be in all respects better than our own. Others, on the ground that there is no provision in the compound eye for the formation and reception of a distinct image, conclude that insects perceive the form of objects very imperfectly, though they are able to realise the smallest motion within their field of view. On the whole, it seems that the structure of the

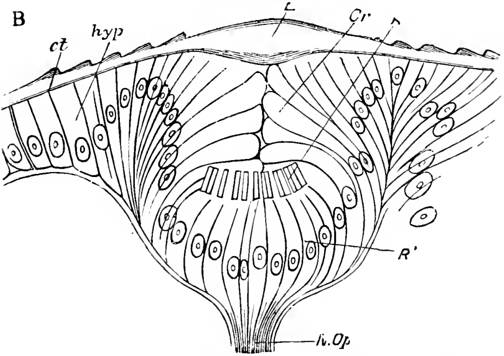


FIG. 32.—Section through an insect's simple eye. *L.* lens; *Cr.* crystalline cones; *R.* nerve-rods; *ct.* cuticle of head; *hyp.* hypodermis cells; *N. Op.* optic nerve. From Miall & Denny, after Grenacher.

compound eye marks it as specially adapted for perceiving sensations of light and motion rather than of form. The appreciation of motion must be of the first importance in enabling the insect to govern its flight, whether the object of the flight be escape, pursuit, or love; while imperfection in the perception of form must be largely compensated by the extreme sensibility of insects to scents, their sense of smell

being developed to a degree almost inconceivable by us. There is reason to believe that the compound eyes do not perceive objects at a greater distance than six feet; while there is no doubt that they are able to appreciate colour sensations, since experiments have proved that insects distinguish between colours, and that they show preference for some colours over others (**1, 21, 22**).

Ears.—The ears of insects are far less conspicuous than their eyes; indeed it is only in a few cases that evident organs of hearing are to be found, and none seem to have been observed in the Cockroach. In many insects, however, fine rods have been noticed hung between two points of the skin in various segments of the body and limbs (**23, b**). These rods are connected with nerve fibres and are believed to receive and transmit sound-vibrations; they are known as *chordotonal organs* (fig. 33 *D*). In the long-horned Grasshoppers and Crickets a number of such rods are found associated together, forming with other structures a complex ear (figs. 29 *F*, 34), which is situated in the front shin just below the knee-joint. The shin, in these insects, is seen to be swollen at this region, and two slightly curved slits (fig. 34 *aa*) run lengthwise along the swollen part. These slits open into chambers formed by the inpushing of the skin of the leg; the chambers are thick-walled outwardly, but their inner walls are thin, forming two oval drums, each of which is in contact with the wall of an air-tube, the main air-tube of the leg dividing into two branches which join again lower down. Along the outer wall of one of these branches runs a ridge (fig. 34 *ca*) in which are arranged, in linear series, the cone-shaped endings of the nerve-fibres, each capped by a large cover-cell; these nerve-endings and their cover-cells decrease in size from top to

bottom of the series which stretches parallel to, and about as far as, the longer axis of the drum. At the upper end of the ridge is a special group of nerve endings (fig. 34 *i. o.*), stretched between points of the skin of the leg and connected with nerve-cells and fibres. Above the drum are two groups of elongated

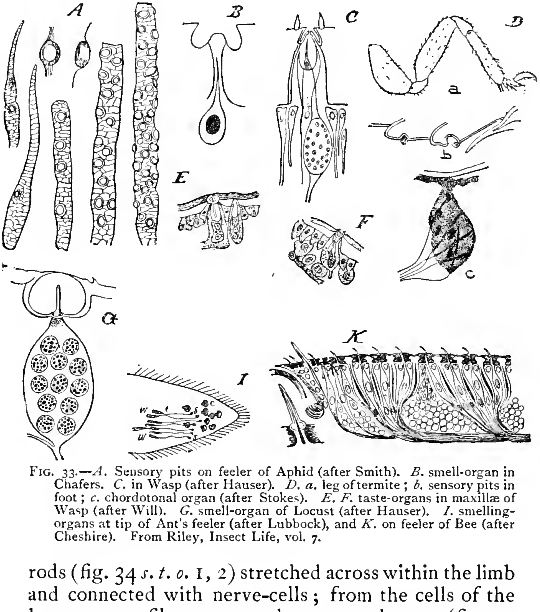


Fig. 33.—*A*. Sensory pits on feeler of Aphid (after Smith). *B*. smell-organ in Chafers. *C*. in Wasp (after Hauser). *D*. *a*. leg of termite; *b*. sensory pits in foot; *c*. chordotonal organ (after Stokes). *E*. *F*. taste-organs in maxillæ of Wasp (after Will). *G*. smell-organ of Locust (after Hauser). *I*. smelling-organs at tip of Ant's feeler (after Lubbock), and *K*. on feeler of Bee (after Cheshire). From Riley, Insect Life, vol. 7.

rods (fig. 34 *s. t. o.* 1, 2) stretched across within the limb and connected with nerve-cells; from the cells of the lower group fibres pass to the tympanal nerve (fig. 34 *t. n.*) which receives also the nerve-fibres from the

ridge. But the fibres from the cells of the upper group of rods (supra-tympanal organ) pass into a special supra-tympanal nerve (fig. 34 *s. t. n.*) (23, a, 24).

In Locusts and short-horned Grasshoppers a large ear is situated on either side of the foremost segment of the hind-body. It consists of a tense, ovate

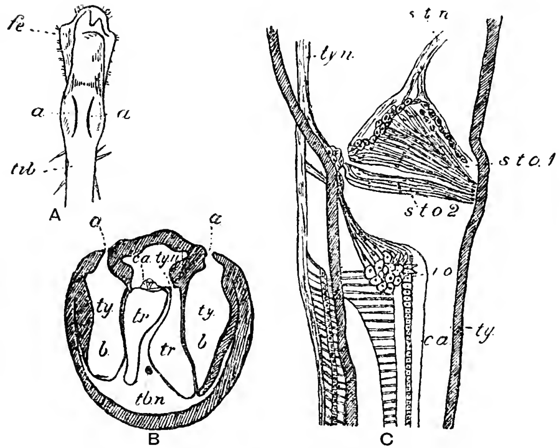


FIG. 34.—Ear of long horned Grasshopper. *A*. Sketch of knee-joint showing position of ear-slits (*a. a*); *fe.* thigh; *tib.* shin. *B*. Cross section of shin. *C*. Longitudinal section; *a.* outer openings; *b.* outer chambers; *ty.* drum; *c. a.* ridge (crista acustica); *tb. n.* tibial nerve; *ty. n.* tympanal nerve; *st. n.* supra-tympanal nerve; *tr.* air-tubes; *s. t. o.* 1, 2, upper and lower divisions of supra-tympanal organ; *i. o.* nerve-endings (intermediate organ). From Carpenter (after Von Adelung), Natural Science, vol. 2.

membrane or drum surrounded by a firm ring. On the inner face of the drum are two horn-like processes to which is attached a delicate bag full of clear fluid. Connected with this are a number of rod-like nerve-endings, whence fibres lead through a nerve-centre

situated on the inner face of the drum to the auditory nerve (fig. 29 *G*) (23, a).

In many Flies (the Blowfly for example) a somewhat similar circular drum, in connection with air-spaces and nerve-endings, is situated in a cavity beneath the base of each wing. Above this drum, under the scutellum, is a supra-tympanal organ, like that of the long-horned Grasshoppers described above. Moreover, chordotonal organs are found in the stalked knobs or "balancers" which represent the hind-wings of Flies. These insects have, therefore, a complex set of hearing-organs, and the fact that the removal of their "balancers" destroys their power of flight, suggests that the delicate sensations which they thus receive are of the greatest use to them in co-ordinating their movements (4).

A very beautiful ear is found in the second segment of the feeler in many insects; this organ is most perfectly developed in the males of certain Gnats and Midges. The segment is greatly swollen and cup-shaped, and somewhat concave on its outer face, where around the base of the next succeeding segment is a ring-shaped plate or drum, which is produced inwardly into numerous processes. These are connected with long rod-like cells united by means of nerve-fibrils with large nerve-cells, which are arranged within the outer wall of the swollen segment and connected with large offshoots from the main nerve of the feeler (fig. 35). In the females of these insects a similar organ is present, but not in nearly so high a state of perfection as in the males. It is evidently of service to the male in enabling him to find a mate. The fine hairs on the shaft of the male's feelers are known to vibrate to the note produced by the humming flight of the female, and to vibrate most strongly when the path of the sound cuts them at right angles—that is,

when the sound comes from the direction whither the feeler points. Hence a male is able to estimate very exactly the direction in which a female is to be found (25).

As might be expected, many of the insects which have well-developed ears are able to make audible sounds. The shrill chirping of crickets and grasshoppers for instance, produced by the rasping of hard teeth over ridges or roughened surfaces, is associated, as we have seen, with very perfect organs of hearing, which enable the insects to appreciate each others' songs.

Organs of Touch. — An insect, clad for the most part in a firm armour of chitin, receives touch - sensations by means of its hairs. Various parts of the body are more or less covered with hairs, some of which have a special sensory function. At the base of every hair is a generating cell by whose activity it has been built up. A nerve-fibril beneath the skin expands into a nerve-cell, whence a fine filament passes through the generating cell, whose substance forms a protecting sheath, into the cavity of the hair (fig. 29 *E*). These sensory hairs are specially numerous on the feelers and the palps. No one who has observed an insect exploring the space in front

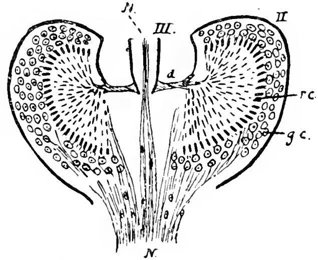


FIG. 35.—Section through second antennal segment of a Midge. II. Cuticle of 2nd segment; III. base of third segment; *d.* drum. *N.* Antennal nerve; *g. c.* ganglion cells; *r. c.* rod-shaped cells. Magnified 200 times. After Child, Zeits. wissen. Zoolog., vol. 58.

with its feelers, and trying the surface over which it walks with its palps, can doubt that the creature gets much information as to its surroundings from its sense of touch.

Organs of Smell. — But the feelers are the principal seat of another sense of the highest importance in the life of the insect. After lengthened discussion and many researches, no doubt remains that they contain organs of smell. Rods covered with strongly-scented acids, when brought near insects, cause the feelers to be moved with energy, and subsequently to be cleaned by being drawn through the mouth. On the other hand, carrion-eating insects, deprived of their feelers, are unable to find their favourite food. Microscopic examination shows the minute structure of the smelling organs. Certain parts of the feelers are covered with tiny pits (fig. 33 *A*) formed by inpushing of the skin, and sometimes protected by pegs or teeth. The pits are filled with fluid and contain rod-shaped cells in connection with large nerve-cells (fig. 29 *C*, 33 *B*, *C*, *G*, *K*) whence fibrils lead the impressions to the main nerve of the feeler, and so to the brain. It has been calculated that 1300 of these smelling pits occur upon a single segment of the feeler in a Hornet, and as many as 13000, in the whole feeler. They are still more numerous in those insects whose feelers are complex in structure—serrate, branched, or feathered; nearly 40,000 are present on each feeler of a male Cockchafer. Organs of similar structure have been observed on the palps of various insects, as well as on the abdominal cercopods in Cockroaches, Crickets and Lacewing flies (fig. 29 *D*). But experiments seem to show that the feelers are pre-eminently the seat of the sense of smell (**2**, **26**).

Organs of Taste.—It is a matter of common

observation that insects are attracted by sweet or by pungent substances, and experiments have proved that they exercise selection in their feeding, guided presumably by a sense of taste. In the Cockroach, on the epipharynx, a number of pits have been observed, containing nerve endings somewhat like those just described as receiving smell sensations. There can be no doubt that these are organs of taste, and they are found in a similar situation in many other insects. They have also been observed on other parts connected with the mouth—on the inner surfaces of the maxillæ in Wasps for instance (fig. 33 *E*, *F*) and at the tip of the tongue in Ants, Bees, and Flies (2, 27).

Muscles.—The movements of insects, as of all complex animals, are due to the action of special bundles of contractile fibres called muscles. A muscle may be readily split into fibres running lengthwise, and each fibre is as a rule surrounded by a thin transparent sheath (*sarcolemma*), the space within which is divided into compartments by a number of membranes stretched across. Each compartment is nearly filled by the true muscle-substance, forming a contractile disc, made up of a bundle of numerous many-sided fibrils. The series of transverse compartments containing the muscle-substance gives an appearance of cross-striation to the fibres when seen under the microscope (fig. 44 *a*, *m*). Hence this muscle is called "striped," and with very few exceptions all the muscles of insects are of this type. In backboned animals, on the other hand, while the heart-muscles and the muscles whose contractions cause the voluntary movements of the body are striated, those of the food-canal are unstriated—that is, the fibres are made up of bundles of continuous fibrils and are not cut into discs by transverse membranes.

Having thus briefly noted the minute structure of insect muscle, we turn to consider the arrangement of the muscles in the cockroach. In our own bodies, as in those of all back-boned animals, the muscles surround the hard skeleton, to various parts of which they are attached. But in insects, as in all arthropods, the hard skeleton is formed from the outer skin; consequently the muscles are fixed to the inner surfaces of the body and limb-segments, which they move.

If a Cockroach's body be opened (fig. 36), a sheet of muscle, divided transversely into sections, is seen on either side of the nerve-cord, stretched lengthwise along the lower wall of the abdomen, from the front edge of the second sternite to the front edge of the seventh; these are the *longitudinal sternal* muscles of the abdomen. Beneath the upper wall of the abdomen, a series of *longitudinal tergal* muscles is seen (fig. 37), each set connecting the front edge of a segment with the front edge of that next behind; it is evident that the contraction of these longitudinal muscles tends to telescope the segments one into the other. Very short muscles (*oblique sternals*) connect the adjacent edge of the sternites of the abdomen, while corresponding ones above (*oblique tergals*) join the edges of the tergites; these probably serve to bend the abdomen towards the side. Each tergite is connected with its corresponding sternite by a *tergo-sternal* or expiratory muscle; it is clear that the contraction of these must bring the upper and lower walls of the abdomen closer together—that is, their action lessens the capacity of the abdomen (see figs. 36 and 37).

In the thorax, on account of the modification of the segments and the presence of legs and wings, the arrangement of muscles is more complicated. Sets of longitudinal tergals are present, similar to those

of the abdomen, but narrower; there are also sets connecting the middle of each tergite with the front

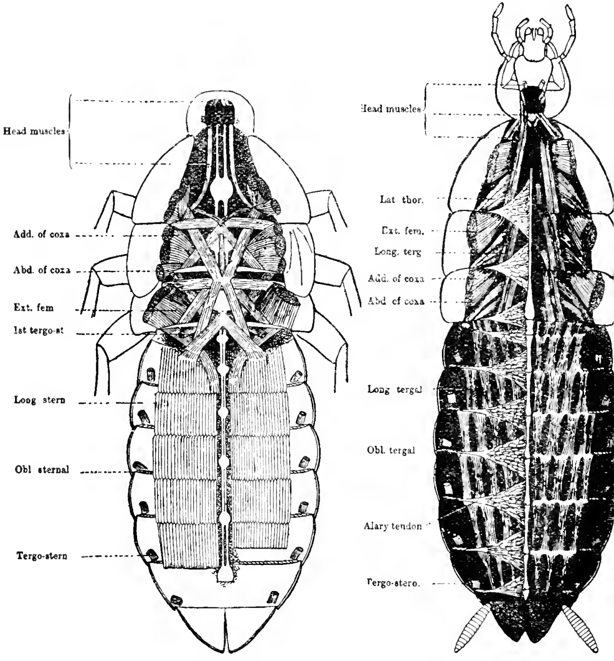


FIG. 36.—Ventral muscles and nerve cord of Cockroach.

FIG. 37.—Dorsal Muscles, Heart and Pericardial tendons of Cockroach.

Magnified $2\frac{1}{2}$ times. After Miall & Denny.

edge of the tergite next behind. The powerful

muscles for moving the legs are attached on either side of each tergite towards its front edge (fig. 37); the other ends of two of these (*adductor* and *abductor coxals*) are attached within the haunch; the third (*extensor femoral*) passes through haunch and trochanter, its far end being attached to the inner edge of the thigh, which the muscle by its contraction stretches out. The other important muscle for moving the thigh (*flexor femoral*) is attached within the outer face of the trochanter, its fibres converging to a tendinous insertion at the outer edge of the thigh. Within the thigh are the muscles for moving the shin, the fibres of the extensor being fixed along the outer, those of the flexor along the inner, edge; the far ends of these muscles converge to tendons which are attached to the near end of the shin. Muscles for moving the foot are fixed along the inner face of the shin, the fibres of the flexor converging into a tendon which passes through all the segments of the foot to the insertion of the claw, while the two muscles which swing the foot backwards and forwards parallel to the axis of the body are attached respectively to the hind and fore edge of the near end of the first tarsal segment (fig. 38).

In describing the skeleton of the thorax, mention was made of the apodemes and forks of the lower wall. The two apodemes are connected by a central longitudinal muscle. To the front one are attached also three pairs of muscles, two pairs connecting with the bases of the front and middle legs, and the third with the arms of the fork behind the mesosternum. The hinder apodeme has four pairs of muscles attached to it, two pairs connecting with the bases of the front and middle legs, one with the arms of the fork of the metasternum, and one with the second sternite of the hind-body. These muscles, with

others which are attached to the forks, bring about motion between the various segments of the thorax. The muscles which move the wings are attached to the lower region of the thoracic wall, and pass thence upwards, those (*elevators*) which by their contraction raise the wing being fixed to the wing-root at a point inside the fulcrum of its attachment to the body, while those (*depressors*) whose contraction lowers the wing are attached to the wing-root outside the fulcrum.

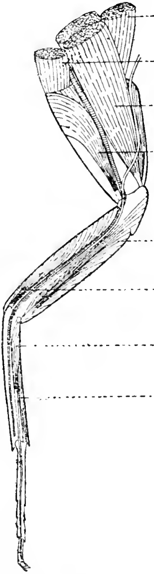


Fig. 38.—Muscles of Cockroach's left leg of middle pair. Magnified. After Miall & Denny.

From the prothorax, slender muscles for moving the head pass forward and are attached to the head-capsule, within which are found sets of muscles acting on the feelers and jaws (1). The muscles of the heart and food-canal will be considered in connection with those organs.

The arrangement of muscles thus briefly described, as found in the cockroach, becomes modified in many respects in other insects. For instance, in most Flies, Ants, Bees and their allies there is much less motion between the segments of the hind-body than in the cockroach, while between the segments of the

thorax there is no motion at all. The female cockroach has vestigial wings, and the male is but a poor flyer; consequently the muscles of flight are very imperfectly developed, as compared with what we find in such highly-organised insects as Dragonflies, Houseflies and Bees. In dragonflies each wing is provided with three muscles for raising and five for depressing it; they act on the wing by means of a long lever in connection with a highly complicated system of sclerites (3, 16).

Blood-system.—The course of the blood in an insect differs considerably from that with which we are familiar in back-boned animals. In our own bodies the blood circulates entirely within a system of closed vessels, but in insects there is only a single vessel running from end to end of the body beneath the back; the blood is propelled forwards through this and then passes into the body-cavity, completely surrounding and bathing the various organs. The cockroach's blood is colourless; in some insects it is coloured green, violet, or red. The blood of insects contains cells which change their form, comparable to the white corpuscles of our own blood.

Heart.—In the Cockroach the greater part of the single vessel forms the heart, which may be described as a long tube with thin muscular walls made up of thirteen chambers; these are separated from each other by valves (fig. 37). Ten of these chambers correspond to the segments of the hind-body, and three to those of the thorax. At a junction between two chambers, the upper wall of the forward one projects above that of the hinder in a kind of pouch (*median lobe*), while the side walls of the forward chamber form two side pouches (*lateral lobes*) also projecting backwards; in the angles formed by these are inlets from the surrounding space into the cavity

of the heart. These inlets, as well as the passage from chamber to chamber, can be closed by a valve which hangs from the upper wall, and allows a forward, but not a backward flow of blood (fig. 39). The heart has no opening at its hinder end, but from the foremost chamber a slender tube—the aorta—passes forward to the head (**1, 30**).

Aorta.—In most insects the blood-tube is only chambered in the abdomen so that the aorta is said to extend throughout the thorax (fig. 47 *d. v.*). In the neighbourhood of the brain the aorta ends in a trumpet-shaped opening. A special contractile sac is situated at the base of each feeler, into which it propels blood received from the head-cavity (**32**).

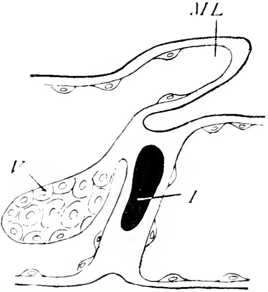


FIG. 39.—Diagram of junction between two chambers of Cockroach's heart. *ML.* median lobe; *V.* valve; *I.* lateral inlet Magnified. From Miall & Denny.

Pericardium.—The heart lies in an irregular chamber—the pericardium—which is bounded above by the upper body-wall and its muscles, and below by a delicate perforated membrane (*pericardial diaphragm*). The cavity is mostly filled with fatty tissue, and is traversed by air-tubes. Below, and supporting the perforated membrane, are a series of muscles (*alary muscles*) (fig. 37), a pair to each segment of the body. Each alary muscle is attached by a tendon to a point at the outer region of the front edge of each tergite. Its fibres spread in a fan-like manner, joining those of its fellow of the pair in the

central line of the pericardium below the heart (1, 2, 30, a).

Circulation.—It is now possible to trace the course of the blood as it circulates. In living, transparent insects the flow of the blood from behind forward through the heart and aorta can be watched through the skin. The blood passes through the opening of the aorta into the body cavity, where it bathes and nourishes the various organs, receives food-substance from the food-canal, gives up its waste matters to the kidney-tubes and air-tubes, receiving pure oxygen from the latter. Then it passes upward through the perforated membrane into the pericardium, whence by the series of paired slits it finds its way back into the cavity of the heart. From the body-cavity the blood flows into the various appendages—legs and wings. In the wings it circulates through the nervures, where, in some cases, it surrounds air-tubes. In the hind wings of the male cockroach the blood has been observed to flow outwards along the nervures near the two margins and to return by the central nervures (29). Some water-bugs have a special pulsating organ at each knee-joint, which assists the flow of blood through the legs (31). In dragonflies and locusts there is a pulsating diaphragm stretched across within the lower wall of the body, forming a special blood space around the nerve-cord (30, b).

Body-cavity.—It has been stated that the blood in insects flows through the body-cavity, which, as we shall see when we consider its development, is very different in its origin from the body-cavity of back-boned animals. It may really be regarded as a collection of blood-spaces (60). Within the body-cavity of the cockroach, surrounding the food-canal and other organs, is to be noticed a large irregular white mass—the fat-body.

Fat-body.—If a portion of this be examined microscopically, it is seen to be made up of polygonal fat-cells with large nuclei. In portions of the tissues, however, the cell-boundaries have become indistinct, the nuclei broken down, and the protoplasm replaced by granules and crystals of waste-matter (urates) derived from various parts of the body. These old cells burst and their contents are absorbed by the blood-currents and carried to the kidney-tubes by which they are passed out of the system (1). The fat-body is an organ of great importance to the insect on account of the chemical changes which take place in its substance; it is most highly developed in long-lived insects. The light emitted by Glow-worms, Fireflies, and other luminous insects is due to chemical activity in a specialised portion of the fat-body, which forms a "phosphorescent organ" with an inner opaque and an outer transparent layer (34).

Air-tubes.—Examination of the body of a cockroach shows us a pair of small oval holes, situated on each of the two hindmost thoracic, and the first eight abdominal segments just beneath the tergites. These are the openings by which the insect breathes, the *spiracles* through which air passes into the complex system of tubes (*tracheæ*), which ramify throughout the body, being accordingly everywhere surrounded by the blood. The seven hinder spiracles on each side are connected by a stout air-tube, passing along the side of the abdomen. From these, as well as from the three foremost spiracles, branches run upwards and downwards, connecting with paired trunks running lengthwise near both the upper and lower body-walls, so that the arrangement of tubes resembles a series of loops or a ladder-like network (fig. 40). Tubes branch in a complex manner over the surface of the food-canal, while large trunks

pass to the head, legs and wings, breaking up into minute branches and ramifying to the farthest parts of the appendages (fig. 41).

Microscopic study of an air-tube shows that its

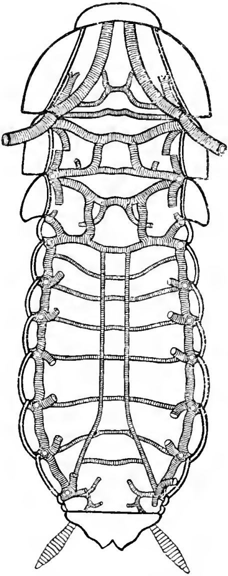


FIG. 40.—Ventral portion of air-tubes in Cockroach. Magnified $2\frac{1}{2}$ times. After Miall & Denny.

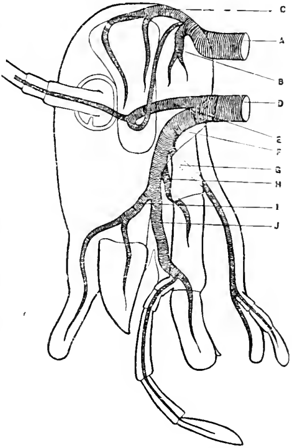


FIG. 41.—Air-tubes in head and jaws of Cockroach. *A. D.* main paired trunks; *C.* branch to brain; *E.* to feelers; *F.* to jaws; *G.* to 2nd maxillæ; *H. J.* to 1st maxillæ; *I.* to mandibles and labrum. Magnified $7\frac{1}{2}$ times. From Miall & Denny.

wall is composed of three layers, a thin outer basement membrane, a central layer (epithelium) of large polygonal cells and an inner layer of chitin, con-

tinuous with that of the outer skin, of which the air-tubes may be regarded as inpushings. In the smallest tubes the chitinous lining is of even thickness throughout, but in the trunks and larger branches it is strengthened by thread-like thickenings on its inner surface. In the large tubes close to the spiracles, these thickenings form polygonal areas of network, but throughout the greater part of the tracheal system, the threads are arranged spirally—not forming a continuous spiral, but interrupted after a few turns around the tube.

In insects of active flight, such as Dragonflies, some Beetles, Bees, Moths and Flies, the tracheal system consists not only of tubes, but of swollen air-sacs, whose walls contain no spiral thickening. In the Cockchafer, the branching tubes, in all parts of the body, swell into numerous pear-shaped air-sacs. In the Bee, there are two great sacs, extending, one on either side, along the greater part of the hind-body. The purpose of these air-sacs is to increase the breathing capacity of such insects of active flight as require a larger supply of oxygen than is sufficient for a ground insect like the Cockroach (2).

Spiracles.—The spiracles on the thorax of the Cockroach are comparatively large openings, with valves attached to the lower margin. By the action of special muscles, these valves can be made to close the outer opening. The spiracles of the abdomen, on the other hand, have an outer elliptical hole always open, leading into a shallow cavity, whose inner wall is pierced by an elongate slit giving access to the air-tube. This slit divides the cavity of the spiracle into two unequal portions, the larger swelling at one part into a pouch, the smaller being strengthened by a bent rod—the bow. The muscle for closing the slit of the spiracle is stretched between the pouch and

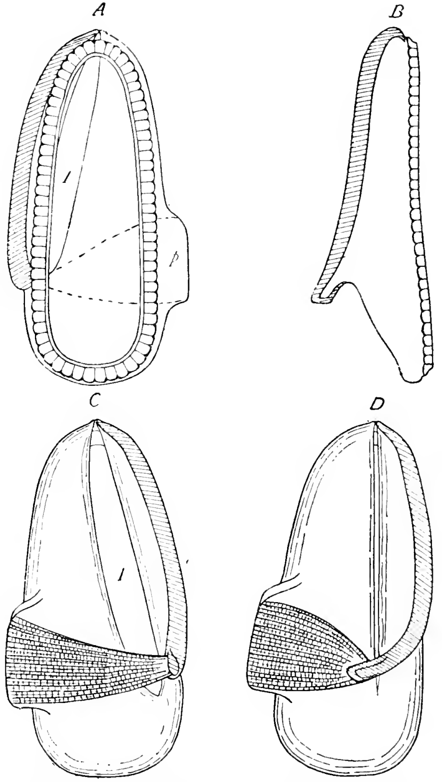


FIG 42.—First abdominal spiracle (left side) of American Cockroach. *A*. from outside, open; *B*. side view in section; *C*. from inside, open; *D*. from inside, shut. The bow shaded in all the figures, the muscle shown in *C*. and *D*. *I*, the inner opening; *p*. the pouch. Magnified 70 times. From Miall & Denny.

the bow; its contraction draws the latter inwards and brings the two edges of the slit into contact (fig. 42) (I, 35).

Respiration.—The set of muscles which contract the cavity of the hind-body have already been described. These are directly concerned in the act of breathing. It has been observed that the hind-body contracts by the action of these muscles causing approximation of the upper and lower walls, and expands by the elasticity of its tissues. The closing of the spiracles is of great importance in the breathing of insects, for it is believed to ensure the passage of fresh air into the finest tubes of the tracheal system, owing to pressure from the abdominal muscles on the air within the tracheal trunks. Were the spiracles constantly open, this air would be simply driven out again and would never reach the minute thin-walled tubular branches where the exchange of gases goes on most actively, oxygen being supplied to the blood and carbonic dioxide given off. The branching of the air-tubes throughout the body in insects is correlated with the absence of a branching tubular blood-system. The blood, diffused through the body-spaces, is everywhere in contact with the air-tubes (I, 37).

Tracheal Gills.—Some Stoneflies, which spend much of their time in wet hiding-places, are believed to breathe the air dissolved in water by means of tracheal gills—bunches of filaments which contain air-tubes, attached in pairs to the various body-segments. This method of breathing, very rare in adult insects, is exceedingly common in many immature forms whose habits are aquatic. These will be referred to at length in later chapters.

Food-Canal.—The organs concerned with feeding and digestion occupy a large space in the body-cavity of most insects, forming a long, more or less coiled,

tube which stretches from the mouth, where food is taken in, to the vent, situated at the extreme hinder end of the abdomen, where waste-matters are cast out of the body.

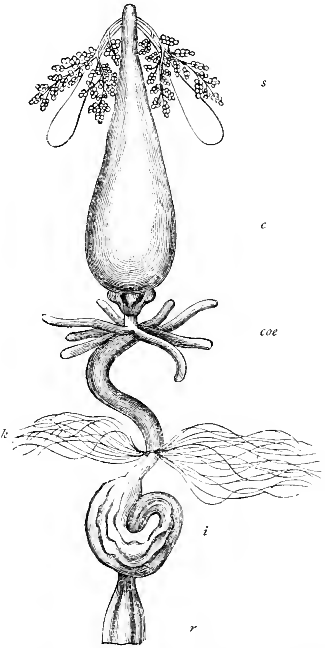


FIG. 43.—Food Canal of Cockroach. *s.* Spittle glands and reservoir; *c.* crop (the gizzard below it); *coe.* coecal tubes (below them the stomach); *k.* kidney tubes; *i.* intestine; *r.* rectum. Twice natural size. From Miall & Denny.

If a Cockroach's body be opened, the food-canal (fig. 43) is seen to occupy a central position lying below the heart and above the nerve-cord. It is readily divisible into various regions. The mouth leads into a narrow gullet (*œsophagus*), surrounded by the nerve-ring of the head, passing backwards through the neck into the thorax, where it gradually swells out into the large, pear-shaped crop, which stretches into the front part of the abdomen.

Crop.—The crop, as well as the gullet, has thin walls which are composed of three layers—an outer muscular layer consisting of striated fibres, arranged lengthwise and

crosswise at right angles, a middle epithelial layer of large rounded or oval flattened cells, and an inner layer of chitin (continuous with the outer skin) whence hairs project into the cavity of the organ.

Gizzard.—Behind the crop comes the gizzard, which is small and bluntly conical, its base being attached to the crop. Its walls are exceedingly thick, consisting largely of muscles whose fibres are arranged circularly. The inner lining is chitinous and is deeply folded so as to form six large teeth, which project far into the cavity of the gizzard, their points nearly meeting in the centre (fig. 44). Behind

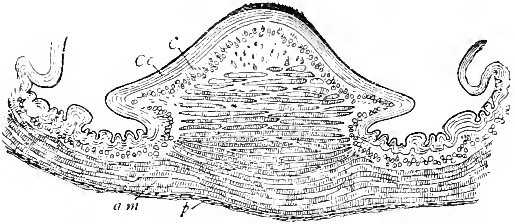


FIG. 44.—Cross section through part of Cockroach's gizzard, showing one tooth and two intermediate spaces. *Cc.* Chitinous lining; *C.* layer of chitin-forming cells; *am.* muscles; *p.* peritoneal layer. Magnified 75 times. From Miall & Denny.

the teeth the folds of the chitinous lining form ridges beset with numerous hairs. The gizzard ends behind in a narrow neck which projects into the cavity of the stomach.

Stomach.—The stomach is a simple tube whose walls consist of an outer, thin, muscular layer, and an inner layer of elongate epithelial cells, which are often clustered together so as to form ridges (fig. 46). From the front end of the stomach open eight short blind tubes (*cæcal tubes*) whose walls show similar structure.

Intestine.—At its hinder end the stomach leads into the short, narrow, *small intestine* whose structure resembles that of the gullet and crop; like those organs and unlike the stomach, it is lined with chitin. At the junction of the stomach and small intestine, the kidney tubes, to be considered later, open. The small intestine passes into the large intestine, the front part of which, the *colon*, is coiled and has its walls, lined inside with chitin, thrown into longitudinal folds. The *rectum*, or hindmost part of the intestine, is also lined with chitin and its walls show six prominent ridges projecting into the cavity, due to the folding of the epithelial layer which is separated into six discontinuous bands, so greatly bent that triangular spaces, wherein nerves and air-tubes ramify, are present between the bands and the muscular layer (fig. 45) (1).

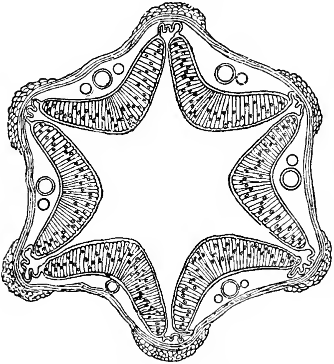


FIG. 45.—Cross section through Cockroach's rectum. Magnified 50 times. From Miall & Denny.

Divisions of the Food-canal.—We have seen that the front and hind regions of the food-canal—the gullet, crop, gizzard, and intestine—are lined with chitin, while the central portion (stomach) is not. Thus there is a threefold division of the tube—a fore-gut (*stomodæum*), including the gullet, crop and

gizzard; a mid-gut (*mesenteron*), comprising only the stomach with its blind tubes; and a hind-gut (*procto-*

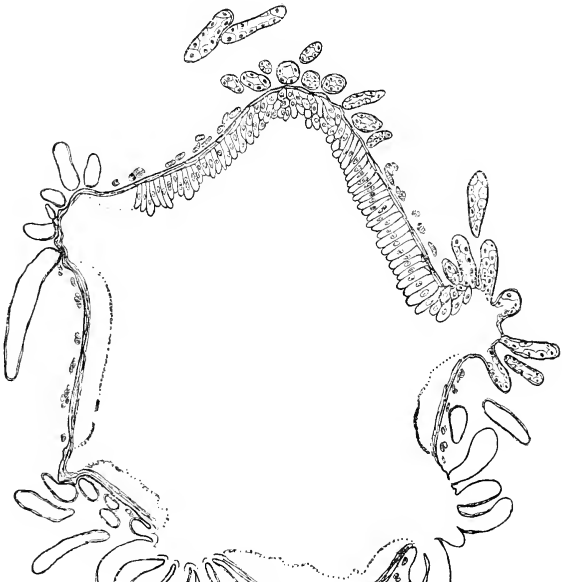


FIG. 46.—Cross section through Cockroach's stomach and kidney-tubes. Magnified 70 times. From Miall & Denny.

dæum), including the small intestine, colon and rectum.

The fore-gut and hind-gut, lined with the same hard substance which covers the outside of the body, are to be regarded as inpushings of the outer skin. Their extent is much greater than that of the stomach, and such a food-canal, formed for the most part by the outer skin turned inwards, is characteristic of the whole group of Arthropods.

Functions of its Parts.—The food of the Cockroach, having been passed from the mouth and gullet into the crop, is subjected there to the action of the spittle, which changes starch into glucose. The glucose is absorbed in the crop and passes through its walls into the blood-spaces. The gizzard has often been regarded as a crushing organ, as might readily be supposed from its strong internal teeth. But it is now generally believed to act only as a strainer; its circular muscles, by their contraction, draw the teeth closely together, and prevent the food particles from passing down into the stomach until digestion is completed. The crop is the seat of the digestive process; an acid fluid secreted by the blind tubes is passed up thither through the gizzard, and acts on the food, absorbing fat and converting albuminoids into peptones. After digestion the walls of the gizzard relax and the food is allowed to pass on into the stomach, through whose walls its nutritious substances are diffused to be absorbed by the blood, while the waste material travels on through the intestine to be expelled at the vent (1, 40).

Modification of the Food-canal.—The various parts of the food-canal, just described, are to be recognised in the great majority of insects. The crop and gizzard of Beetles are very similar to those of the cockroach, but the stomach is, throughout its length, beset with numerous blind tubes, while the small intestine is, in some cases, of excessive length. In

some insects which feed by sucking liquid food—Moths, Flies and Bugs, for example—the gullet is expanded just behind the mouth to form a spherical sucking-pump, attached to the head capsule by muscles. This draws in food and forces it backwards into the gullet, which is long and slender and leads directly into the stomach, there being no gizzard, as there is no solid food to be strained. In these insects, just before the gullet joins the stomach it gives off a large pear-shaped or spherical sac often called the "sucking stomach," but now known to be a reservoir for storing food; possibly this organ corresponds with the crop in the cockroach. In Moths it opens out close to the forward end of the stomach, but in Flies it is situated at the end of a long tube (2, 4).

In Bees (fig. 47) and Ants the gizzard of the cockroach is represented by the "honey stomach," which communicates with the stomach by means of a thick-walled "honey-stopper" provided internally with four chitinous ridges set with fine hairs pointing backwards. These can be brought together, like the teeth of the cockroach's gizzard, so as to close the passage, or separated so as to leave a cross-shaped opening. By means of this stopper, solid food such as pollen is separated from the honey as necessity may require.

Spittle-glands.—As mentioned above, the spittle or salivary glands open into the mouth. On either side of the gullet and crop may be seen a gland and its reservoir (fig. 43). The gland is a thin leaf-like mass, composed of two large lobes and a third much smaller. The spittle, secreted by the large epithelial cells of the glandular tissue is led off by tubes or ducts which unite to form a duct with chitinous lining, strengthened by spiral threads like the air

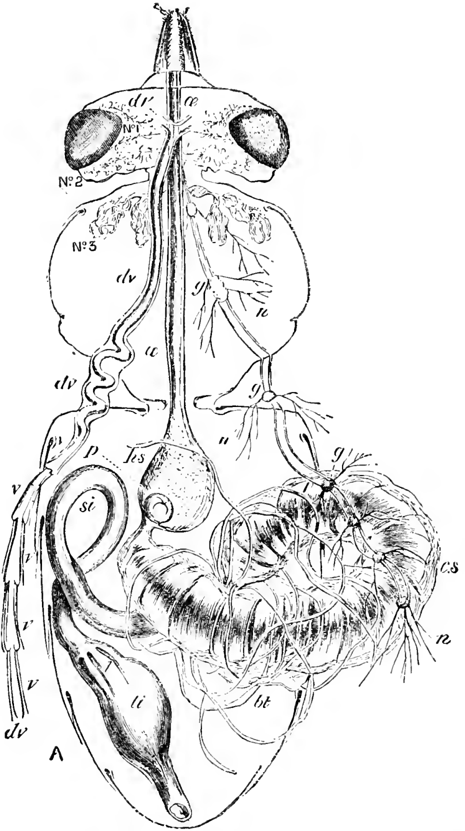


FIG. 47.—Food-canal etc. of Honey-bee. Nos. 1, 2, 3, systems of spittle-glands; *æ*. gullet; *hs*. honey-stomach; *p*. honey-stopper; *cs*. stomach; *bt*. kidney-tubes; *si*. intestine; *li*. rectum; *dv*. heart with its chambers (*v*.) and aorta; *g*. *g*. *g*. *n*. nerve-chain and ganglia. Magnified 10 times. From Benton (after Cheshire), Bull. 1 (n.s.) Div. Ent. U.S. Dept. Agr.

tubes. The ducts from the two glands join to form a single tube, which runs into the large duct formed by the union of those from the reservoirs. These reservoirs are large pear-shaped sacs with transparent chitinous walls (1, 42). Spittle glands are very highly developed in the Bees, some of which have as many as eight pairs, seven small pairs in the head and a large pair in the thorax (fig. 47, Nos. 1, 2, 3).

Scent, Poison and other Glands.—It is well known that Cockroaches give off a disagreeable smell. This is due to the secretion from a pair of glands opening on the back of the hind-body—between the fifth and sixth tergites. Each gland is a pouch formed by inpushing of the skin, lined with chitin and bearing in its cavity many stiff, branched bristles. Surrounding the chitinous lining is the cellular layer which secretes the evil-smelling fluid. Glands, somewhat similar to these, are found on various parts of the bodies of many insects, and their secretion is of use as a defence against enemies; certain Butterflies possess such glands at the hinder end of the abdomen (44). But in other insects the substance secreted is sweet-smelling, and is believed to act as an attraction to the opposite sex; some male Butterflies have patches on the wings which produce sweet scents, others possess fragrant tufts of hairs on the legs (45).

Certain insects discharge fluids not merely unpleasant, but actually poisonous. A lobe of each spittle-gland in Gnats is specially modified for the secretion of the poison to which the well-known painful effects of the bite of those insects is due. A pair of poison-glands are present in the head of some Water-bugs; these open at the base of the beak, and their secretion serves to kill the small insects on which the bug preys. Best known of all poison glands are those connected with the stings of Wasps and Bees.

In these insects two glands are always present, an acid and an alkaline; the former (fig. 51 *p. g.*) may consist of a simple tube, of a bifid tube, of paired tubes, or of a number of tubes; the epithelial coat of these is made up of several layers of cells. They open into a large oval or spherical poison reservoir (fig. 51 *p, b*) whence proceeds the duct to the sting. The alkaline gland is a somewhat thick, irregular tube, whose epithelial coat consists of a single layer of cells,

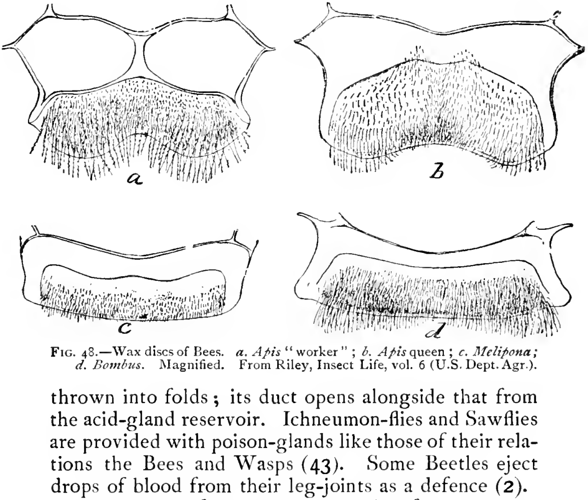


FIG. 48.—Wax discs of Bees. *a. Apis* "worker"; *b. Apis* queen; *c. Melipona; d. Bombus*. Magnified. From Riley, Insect Life, vol. 6 (U.S. Dept. Agr.).

thrown into folds; its duct opens alongside that from the acid-gland reservoir. Ichneumon-flies and Sawflies are provided with poison-glands like those of their relations the Bees and Wasps (**43**). Some Beetles eject drops of blood from their leg-joints as a defence (**2**).

Many insects form a waxy secretion for protection or nest building. Beeswax is a well-known substance used by the insects for making their comb; it is secreted by scale-shaped glands, formed of specially

modified cells beneath the skin, on four of the hind-body sternites (fig. 48). Scale-insects are provided with wax-glands all over their bodies; these secrete a protective covering beneath which the insect lives and shelters. Plantlice too protect themselves by a waxy substance, the so-called "honey-dew," which is secreted by glandular cells beneath the skin, and passed out through two conspicuous tubes — outgrowths from the back of the hind-body.

Kidney-tubes. — The kidney-tubes (*Malpighian tubes*) of the Cockroach open into the food-canal where the stomach joins the small intestine. They are sixty to seventy in number, and exceedingly fine. Microscopic examination shows that each tube consists of a connective tissue layer and a basement-membrane, surrounding large cells which line the interior of the tube (fig. 46). These cells and the central canal contain urate crystals, which are formed by the excretory action of the cells on the blood, and are passed on into the intestine and so cast out of the body. The number of tubes in the adult cockroach is large, as it is in Locusts and their allies, Earwigs, Stoneflies, Mayflies, Dragonflies, Ants, Wasps, Bees, Sawflies, and Ichneumon-flies. But in all immature insects the number is small (4-6), and this condition persists in the adult in Springtails, Booklice, Termites, Bugs and their allies, Lacewing flies, Caddis-flies, Moths, and Beetles. In most insects the kidney-tubes open, as in the cockroach, at the junction of the mid-gut with the hind-gut, in some Bugs they open into the rectum, while in a few Froghoppers they are moved forward to the mid-gut, where they open separately from each other. In some cases, where numerous tubes are present, they are joined in tufts, the ducts from these opening together into the intestine; in the Mole-cricket, all

the tubes unite into a single duct. Generally the length of the tubes varies inversely as their number; in some insects they are excessively long, and coiled around the food-canal (2, 33, 40, 46).

Reproductive Organs.—Having now considered

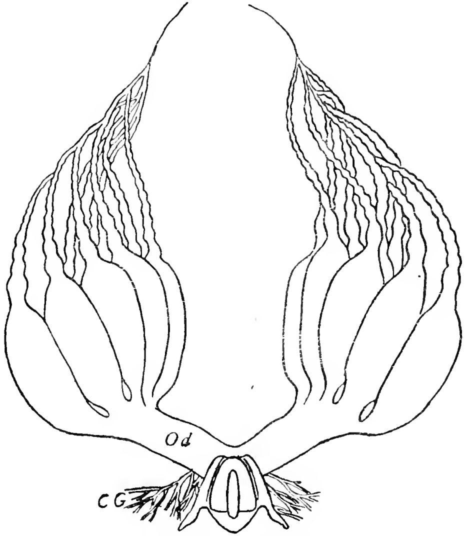


FIG. 49.—Ovaries of Female Cockroach, with oviducts *Od.* and colleterial glands *CG.* Magnified 14 times. From Miall & Denny.

the various organs whose functions contribute towards the individual life of the insect, we turn to those which are concerned with the production of young, which serve to perpetuate the life of the race. In the cockroach, as in most insects and in most other

animals, the union of two dissimilar cells—a small active (male) sperm-cell (*spermatozoon*) with a large, passive (female) egg-cell (*ovum*)—is necessary for the development of a new individual; that is to say, reproduction is sexual.

Ovaries, &c. — The egg-cells are formed in the ovaries of the female. In the Cockroach there is a pair of ovaries (fig. 49) situated towards the hinder end of the abdomen. Each ovary consists of eight ovarian tubes, four above and four below. At their forward ends the tubes of each ovary are exceedingly narrow, and unite into a slender, solid thread, which is attached to the fat-body. In its hinder region each tube swells into a tapering oval form and is often beaded in appearance on account of the eggs which it contains. The eight tubes of each ovary open into an oviduct, and the two oviducts unite centrally to form a short passage (*vagina*) which opens to the outside through a special sclerite situated between the seventh and eighth sternites of the abdomen (fig. 52) (**I, 51**).

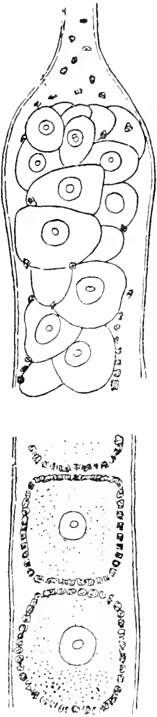


Fig. 50.—Ovarian tube of Cockroach, with scattered nuclei (upper figure) which form follicles round the eggs (lower figure). Highly magnified. From Miall & Denny (after Brandt).

Microscopical examination shows that the wall of an ovarian tube consists of a transparent elastic membrane with cellular lining. In the upper, narrow portion of the

tube, a number of nuclei can be seen, but the protoplasm is not definitely divided into cells. In the lower, wide region, the large egg-cells can be recognised, and as the oviduct is approached, these become arranged in a single row, each being surrounded by a layer of nuclei forming a follicle (fig. 50). By the action of these nuclei the two coatings of the egg are formed—a thin inner membrane (*vitelline membrane*) surrounding the yolk and a firm outer chitinous layer (*chorion*). The latter at one end is perforated with numerous fine pores (*micropyles*), through which sperm-cells have an opportunity of penetrating to the egg.

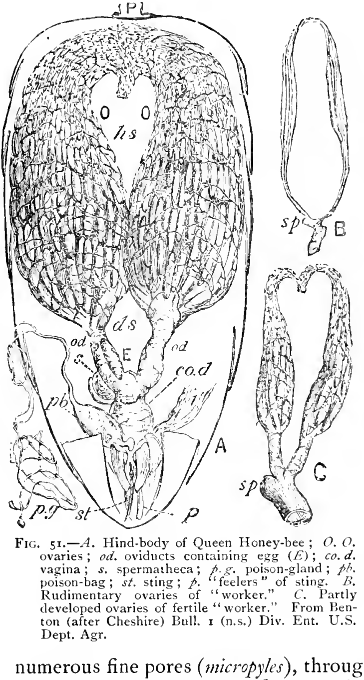


FIG. 51.—*A*. Hind-body of Queen Honey-bee; *O. O.* ovaries; *od.* oviducts containing egg (*E*); *co. d.* vagina; *s.* spermatheca; *p. g.* poison-gland; *pb.* poison-bag; *st.* sting; *p.* "feelers" of sting. *B.* Rudimentary ovaries of "worker." *C.* Partly developed ovaries of fertile "worker." From Benton (after Cheshire) Bull. 1 (n.s.) Div. Ent. U.S. Dept. Agr.

In many insects the arrangement of cells within

the egg-tube is less simple than in the cockroach. Special cells take on the work of nourishing the egg-cells, and these are grouped in "nutriment chambers," which alternate in position with the eggs, their contents being finally absorbed by the latter. Or the forward region of the tube may contain a supply of nutriment-cells which are in connection, by means of fine threads, with the eggs in the hinder region (**2**, **47**, **56**).

The number of tubes to each ovary is frequently eight, as in the cockroach, but it varies greatly in different insects. In some Springtails (*Campodea*), each ovary has but one tube; in the queen Honey-bee there are nearly a hundred (fig. 51), and in a queen Termite fifteen hundred. In Mayflies the two oviducts open separately direct to the exterior (**49**), and there is no vagina.

Vagina.—The walls of the vagina are muscular and are lined with chitin. Into its lower wall open a pair of glands consisting of very fine tubes repeatedly branched; the left gland is much larger than the right. These are the colleterial glands (fig. 49 *C*, *G*); they secrete crystals of oxalate of lime and a fluid which coagulates on exposure. The purse-shaped egg-capsule (fig. 53), or "raft," of the Cockroach is formed from these substances. As mentioned above, the outer opening of the vagina is situated between the seventh and eighth sternites of the hind-body. In the cockroach the eighth and ninth sternites are very small and are withdrawn behind the seventh, which is greatly enlarged and bent upwards so as to enclose a cavity, the genital pouch, on to whose upper wall (through the eighth sternite) opens the sperm-reservoir (*spermatheca*), a short, spiral tube swollen at its blind end, wherein are stored sperm-cells received from the male during sexual

union. These can be discharged into the genital pouch, where they fertilise the eggs, as these are discharged from the vagina.

Ovipositor. — Within the genital pouch of the female Cockroach are three pairs of processes which act as forceps for grasping the egg-capsule. One pair belongs to the eighth segment, being attached to the eighth sternite below, and to both eighth and ninth tergites above. These processes (*anterior gonapophyses*) are broad and flat at the base, becoming slender and bent with somewhat hooked tips. The other two pairs (*posterior gonapophyses*) belong to the ninth segment; there is a large outer pair formed by lengthened processes of the sternite itself, and a small, harder inner pair (fig. 52). These two pairs are situated above the anterior pair, in conjunction with which they form a forceps working vertically. They hold the capsule while it is being formed and filled with eggs, and the impression made on it, while still soft, by the inner hind pair, is to be recognised in its toothed upper edge (fig. 53) (**1**, **51**).

The cockroach's ovipositor is retracted within the abdomen; in many insects, Moths and some Beetles for example, which simply pass out their eggs on to a leaf, its parts are little developed or altogether wanting. In other insects it projects far out beyond the abdomen; its hind inner pair of processes being modified into organs for piercing or cutting substances in which the eggs may be laid, while the forward pair and the hind outer pair form a sheath through which the eggs are passed down. In the long-horned Grasshoppers the ovipositor is sometimes as long as the body; by means of it the female lays her eggs deep in the ground. In Cicads the inner processes are modified into hard blades with toothed edges; these are moved backwards and forwards guided by

the outer processes which act as a support (figs. 54, 55), thus incisions are cut in the twigs on which

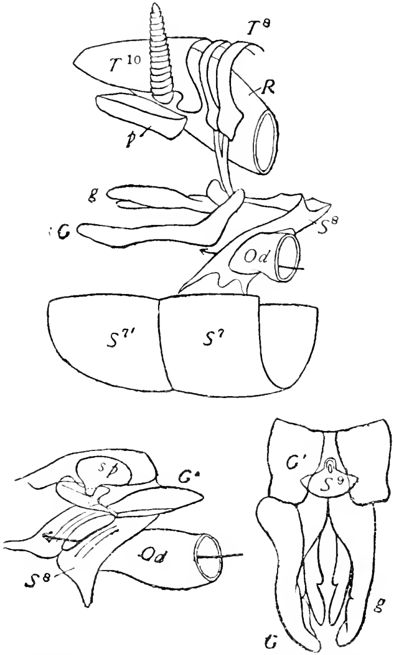


FIG. 52.—Hinder abdominal segments and ovipositor of female Cockroach. *T* 8. *T* 10. 8th and 10th tergites; *S* 7. *S* 7'. 7th sternite; *S* 8. sclerite between 7th and 8th sternites; *S* 9. 8th sternite; *Od.* vagina; *sp.* spermatheca; *G.* anterior, and *g.* posterior gonapophyses. Magnified. From Miall & Denny.

the eggs are laid. Bees, Wasps and Ants have in

connection with the ovipositor the poison glands described above, so that the organ is modified into a sting. The front pair of processes (belonging to the eighth segment) are thick, hairy "feelers," while the four processes of the ninth segment form the actual sting, the outer pair fused together serving as a support or sheath upon which the inner pair—sharp, needle-like piercers with barbed tips—can be pushed in or out. Each lancet is grooved, the groove fitting on a rail-like projection of the sheath. The lancets are also hollowed out along their inner surfaces, so that a tube is formed between them along which the poison flows (fig. 51).

It is believed by many students that the front processes of the ovipositor are the modified limbs of the eighth abdominal segment, while the outer and inner hind processes represent outer and inner divisions of the limbs of the ninth segment (2). But it has been shown by study of the growth of the parts in the female cockroach (51), that the outer hind pair actually represent portions of the ninth sternite, since, in the young insects, they carry at their tips stylets similar to those of the male (p. 31), which disappear in the female when the adult condition is reached. Unless it be denied (50) that the stylets are the reduced limbs of the ninth segment, neither pair of hind processes in the ovipositor can represent those limbs. It has been suggested that the inner hind pair may really belong not to the ninth but to the tenth segment (51, 58), of which they might then be regarded as the limbs, the

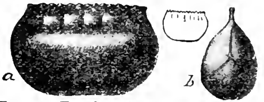


FIG. 53.—Egg-Capsule of American Cockroach. *a.* side view; *b.* end view. The outline shows natural size. From Howard, Bull. 4 (n.s.) Div. Ent. U.S. Dept. Agr.

various abdominal appendages being represented thus :—

VIII. Anterior gonapophyses.
IX. Stylets (outer posterior gonapophyses representing lateral outgrowths of sternite.)
X. Inner posterior gonapophyses.
XI. Cercopods.

Since the inner hind gonapophyses arise in the cockroach behind the ninth sternite, it is conceivable that they may really belong to the tenth segment (**51**). But in all other insects in which the organs have been studied, both inner and outer hind pairs seem to belong undoubtedly to the ninth. It is most likely, therefore, that while the stylets and cercopods represent limbs, the processes of the ovipositor should be regarded as specially modified outgrowths of the skin rather than as true appendages of the segments to which they belong (**59 a**).

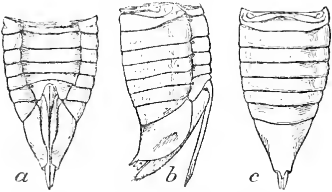


Fig. 54.—Hind-body of female Cicad showing ovipositor. *a.* from beneath ; *b.* from side ; *c.* from above. From Marlatt, Bull. 14 (n.s.) Div. Ent. U.S. Dept. Agr.

Male Reproductive Organs.—The sperm-cells are developed in the genital glands or *testes* of the male ; in the Cockroach these organs lie in the fat-body, beneath the fifth and sixth abdominal tergites. Each testis consists of thirty to forty rounded chambers opening into a slender tube (*vas deferens*), about a quarter of an inch long, which leads into a sperm vesicle (*vesicula seminalis*) (fig. 56). The chambers of the testis are lined with a folded layer of cells (*sper-*

matospores) which divide to form hollow globes (*spermatocysts*) of cells. Within these globes lie the sperm mother-cells (*spermatocytes*), which divide into two and then into four sperm-cells (*spermatoblasts*[1]). These, escaping through the split wall of the spermatocyst, are transformed into the active sperm-cells (*spermatozoa*) (47). Each spermatozoon consists of a nucleated head and a long tail, by whose vibratory action the

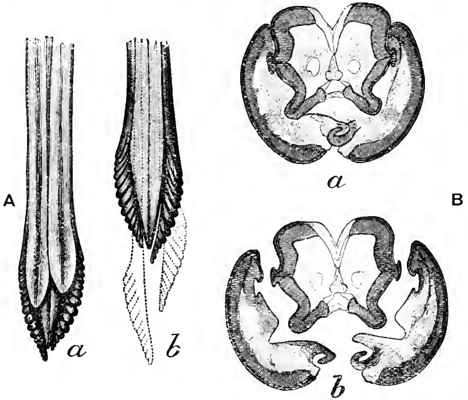


FIG. 55.—*A*. Tip of Cicad's ovipositor, highly magnified. *a*. from above; *b*. from beneath. *B*. Section through ovipositor more highly magnified. *a*. facets in natural position; *b*. separated showing interlocking ridges and grooves. From Marlatt, Bull 14 (n.s.) Div. Ent. U.S. Dept. Agr.

cell is enabled to enter the egg of the female. The male cockroach is remarkable in that his testes shrivel up while he is still immature, the development of the sperm-cells being completed in the vesicles.

The sperm-vesicles are situated close together in the centre of the body, above the sixth abdominal

[1] Or *spermatids*.

sternite. They are rounded chambers beset with numerous tubes (*utricles*), some of which, opening into the sides and hinder parts of the vesicles, are longer and larger than others which open into their forward central region. The two vesicles join to form a common sperm duct (*ductus ejaculatorius*) with muscular walls and chitinous lining, which is swollen at its forward end where the vesicles are, contracted in its

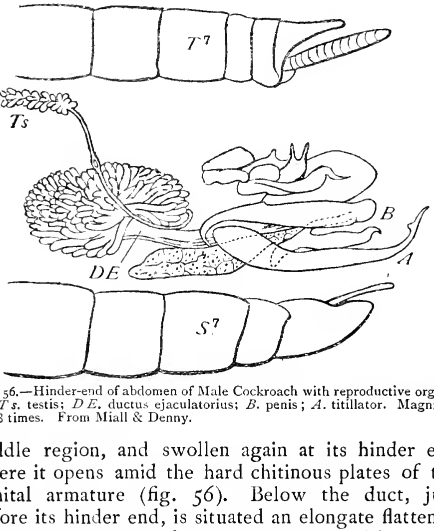


Fig. 56.—Hinder-end of abdomen of Male Cockroach with reproductive organs. *Ts.* testis; *DE.* ductus ejaculatorius; *B.* penis; *A.* titillator. Magnified 8 times. From Miall & Denny.

middle region, and swollen again at its hinder end where it opens amid the hard chitinous plates of the genital armature (fig. 56). Below the duct, just before its hinder end, is situated an elongate flattened *conglobate gland* whose function is unknown (1).

The general plan of the male organs, as just described for the cockroach, is constant in most insects, though there may be considerable variation in the

form of individual parts. The testis is sometimes a simple tube, or consists of a number of branched tubes. In most Moths and in some solitary Wasps and other insects, the two testes are situated close together and enclosed in a common membrane, so that they seem to form a single, unpaired organ. The numerous bushy utricles of the cockroach in which the spermatozoa are stored and associated in bundles preparatory to ejaculation, are represented in most insects by a few long tubes—the *accessory glands*, in which mucus is secreted or packets (*spermatophores*) for the sperm-cells are formed (**2**).

Comparison of the male with the female reproductive organs shows a general resemblance between the two sexes. The ovaries and oviducts correspond with the testes, sperm-tubes and sperm-vesicles; while the vagina is comparable to the sperm-duct, both being lined with chitin and formed by inpushing of the outer skin. In Mayflies the paired sperm-ducts (*vasa deferentia*) open directly to the exterior; while in Earwigs, though the ends of these ducts usually become fused, or one disappears so that there is a single terminal duct, it has no chitinous lining (**49**).

Male Genital Armature.—As in the female insect certain hard chitinous processes at the hinder end of the body form an ovipositor, so the male is provided with a special armature for use in seizing his mate and ensuring the introduction of sperm-cells into her sperm-reservoir. The armature of the Cockroach is concealed within the ninth sternite; it consists of a "titillator"—a long curved process with hollow base and hooked tip, a solid "penis" clubbed at the end, and a number of irregular hooks whose precise functions have not been made out (fig. 56) (**1**).

In many insects paired processes connected with the ninth segment, to which they are hinged, are

greatly enlarged and serve as *claspers*, holding the abdomen of the female during sexual union (fig. 9 *f*). Butterflies and moths have the inner surface of the claspers beset with teeth and ridges (*harpes*), which fit accurately the sculpture on the seventh abdominal segment of the female of the same species (52, 92). In the males of these insects, moreover, the tenth tergite and sternite are specially modified for use as a genital forceps, which works vertically. A very remarkable peculiarity is shown by the male Dragonflies, which have their organs of copulation on the second abdominal segment instead of at the tail-end, like all other insects (fig. 112). The sperm-duct, nevertheless, opens as usual behind the ninth sternite, and the insect is able to bend his long abdomen forward, and so to transfer the sperm-cells to the second segment.

We have seen that the head-segments and their appendages are highly modified in connection with the insect's outlook on its surroundings and its manner of feeding; those of the thorax in connection with the method of its locomotion. The front segments of the hind-body, enclosing the digestive organs, remain simple in form; but the hindmost segments undergo extreme modification so as to ensure those functions of pairing and egg-laying, whereon depend the continuance of the race.

Chapter II

THE LIFE-HISTORY OF INSECTS

> Nature . . . by the water's side,
> Out of the mud drew creeping things,
> And, smiling on them, gave them radiant wings.
>
> —J. H. Ewing.

The Egg.—Having sketched the main features of the structure of insects, we have next to consider the process of growth by which the complex organs of the adult are built up. These organs are, as we have seen, composed of cells or of substances due to the energy of cells. And the innumerable cells in the body of a cockroach, a moth or a bee, have arisen by the division of the egg-cell laid by the mother. The life-story of any insect, therefore, must begin with the egg.

The Cockroach's egg has already been briefly described. It is of elongate shape, like a crescent with rounded ends, one face being convex and the other concave, and of a flattened oval form in cross-section. It is surrounded by a hard outer chitinous coat (*chorion*) and a thin inner yolk (*vitelline*) membrane. The interior is filled with protoplasm charged with coarse granules of the food-yolk which nourishes the growing embryo. Just within the yolk-membrane is a thin layer of clear protoplasm. Easily visible while the egg is still in the ovarian tube, but hidden by the accumulated yolk-granules after laying, is the nucleus of the egg-cell—the *germinal vesicle*, which

contains a still smaller body, the nucleolus or *germinal spot*.

The outer form of insect eggs is exceedingly variable. Very many—as those of Beetles, Grasshoppers (fig. 60) and Flies (fig. 68 *b*)—are elongate like the cockroach's. The eggs of some Moths are globular, while those of Butterflies, and especially those of Bugs, assume graceful flask-like shapes and elegantly sculptured surfaces. Other insects—the Golden-eye flies for example—produce stalked eggs, which are raised well above the plant stem on which they are laid and so protected from mites and other enemies. Insect eggs contain a quantity of food-yolk, and are therefore of comparatively large size. The globular egg of a Hawk-moth, for instance, measures $\frac{1}{20}$ inch in diameter, while the similarly shaped egg of a Cat measures only $\frac{1}{120}$ inch.

As mentioned above, the Cockroach's eggs are protected by a purse-shaped capsule (fig. 53). Sixteen eggs are contained in this case, eight on a side, the convex face of each egg being next to the capsular wall. The eggs are produced alternately from each ovary, those from the right ovary passing to the left of the capsule, those from the left ovary to the right (58 a). Many insects protect their eggs by a gummy secretion; some female Moths shed hairs from their bodies to afford the eggs a covering. Those of water-insects are often contained in a long gelatinous tube, and some water-beetles construct around their eggs a silken cocoon. Locusts, Grasshoppers and many other insects bury their eggs in the ground for safety, other insects—Chafers and Crane-flies, for example—lay their eggs in the ground that the young may be near the roots of plants on which they will feed. Almost universally the food of the young determines the place of egg-laying—the queen Bee

leaves her eggs in the prepared cells, the Ichneumon-fly in the body of the living caterpillar, the Burying-beetle in the dead body of a bird, the Sawfly in the leaf of a plant.

Fertilization.—It will be remembered that into the genital pouch of the female cockroach opens the sperm reservoir, where are stored the active sperm-cells derived from the male insect. As each egg passes from the vagina to its place in the egg-capsule, one of its ends comes in contact with the opening of the sperm reservoir. The hard coat at this end is perforated with a number of minute holes, through which a sperm-cell can make its way into the protoplasm of the egg. Here the nucleated head of the active sperm-cell (*male pronucleus*) unites with the nucleus of the egg-cell (*female pronucleus*) (fig. 57, *A*, *m.f.*). The nucleus (*segmentation nucleus*) formed by their union gives origin by repeated division (fig. 57 *B*, *s.*) or segmentation to the embryo. This union of the male and female elements is known as the fertilization of the egg, and in most insects, as in animals generally, no new individual will be developed if the egg remain unfertilized.

Polar Bodies.—Before fertilization, the nucleus of the egg-cell twice undergoes division, the separated portions, each with a small quantity of protoplasm, being cast out, as the two *polar bodies* or *directive cells* (fig. 57, *A*, *p*1, *p*2). By the separation of these the substance of the nucleus is reduced to a quarter of its original amount. It will be remembered that, in the male, four active sperm-cells are formed by the division of each sperm mother-cell (spermatocyte); and it is believed that when fertilization takes place, the nuclear matter cast out by the formation of the second polar body is replaced by an equivalent amount derived from another individual—the male. The

separation of the polar bodies undoubtedly prepares for fertilization, though their precise meaning is not certainly known. It is generally held that by their formation the substance of the female pronucleus is reduced to the same extent as that of the male pro-

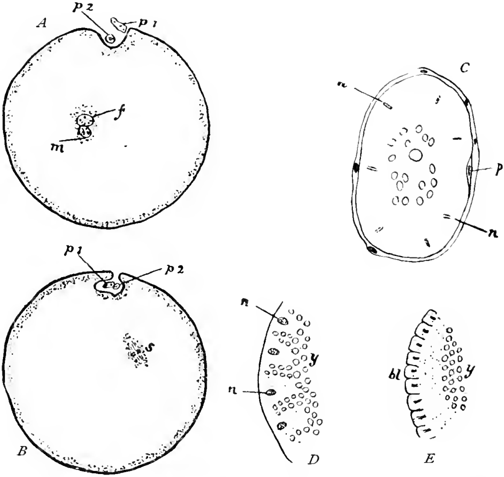


FIG. 57.—*A*. Egg of Plant-bug (*Pyrrhocoris*) showing extruded polar bodies (*p* 1, *p* 2) and union of male (*m*.) and female (*f*.) pronuclei. *B*. Later stage showing re-absorption of the polar bodies (*p* 1, *p* 2) and first division of the segmentation nucleus. Magnified 35 times. After Henking, Zeits. wiss. Zoolog., vol. 54. *C*. Parthenogenetic egg of Aphid showing the single polar body (*p*.) and the nuclei (*n. n.*) arranging themselves around the margin of the egg. Magnified 580 times. *D*. Section through margin of egg of Blow-fly, showing nuclei (*n. n.*) surrounding the yolk (*y*.). *E*. Later stage showing formation of distinct cells of the blastoderm (*bl*.). Magnified 200 times. After Blochmann, Morph. Jahrb., vol. 12.

nucleus, so that the contribution of the two parents towards the segmentation nucleus may be equal.

After fertilization the polar-bodies are, in most insects, re-absorbed into the egg-substance (fig. 57, *B*) (54, 55).

Virgin Reproduction.—Without fertilization, no egg will, as a rule, develop into a new individual, but among insects there are a fair number of exceptions to this rule. Eggs laid by virgin female Moths are known occasionally to develop. In certain Sawflies reproduction by virgin females (*parthenogenesis*) is common, and also in many Gallflies. Males of some kinds of the latter insects have never been discovered, so that sexual reproduction must be excessively rare among them, if it ever takes place at all. The rapid multiplication of Plantlice in summer-time, too well known to gardeners, is due to successive generations brought forth by virgin females. With few exceptions all the eggs which have been studied of insects and other animals capable of virgin reproduction, cast off but a single polar body (fig. 57, *C*, *p*); that is, the halving of the nuclear matter of the egg-cell preparatory to the addition of the nuclear matter of the sperm-cell does not take place as a rule in parthenogenetic eggs. It appears therefore that the amount of nuclear matter present in the egg before the extrusion of the second polar body is enough to start the formation of a new individual. But if this amount be halved (as it invariably is in eggs which develop sexually) reproduction becomes impossible unless the loss is made good by fertilization. But several parthenogenetic insect eggs are known in which two polar bodies are produced. Judging from what occurs in the similar case of the crustacean *Artemia*, it is likely that, in these eggs, the second polar body reunites with the egg-nucleus before segmentation (56). Among Honey-bees the mother insect (queen) is able to lay, at will, eggs either fertilized or unfertilized;

the former invaribly develop into female, the latter into male insects. On the other hand, the successive broods of Plantlice produced through the summer by virgin reproduction consist entirely of females. And among such insects as those Gallflies of which no males are known, the young produced by parthenogenesis are, of course, females. The reason for these cases of virgin reproduction is still a subject of controversy. It is evident that the power must greatly help the insects possessing it to increase in numbers, since no female runs the risk of barrenness through failure to pair. Often, as in the case of the plantlice, this power is associated with a specially abundant food supply, being continued throughout the summer months, but giving way to the usual method of sexual reproduction in the autumn and spring (54, 57).

Development of the Embryo.—By division of the fertilized egg-nucleus are formed the layers of cells whence the various organs of the body are built up. This process is complex, and its details differ in various insects in which it has been observed (53). It has been mentioned that an insect egg is relatively large and contains a quantity of food-yolk. In such eggs the whole mass does not divide into separate cells, but a layer of cells is formed at one side of the egg or around the central yolk. This method of egg division is known as partial segmentation, and eggs which undergo it are called *meroblastic*. It contrasts with the complete segmentation of small eggs without food-yolk—those of mammals and star-fishes for examples, which are called *holoblastic*.

Blastoderm.—The segmentation of an insect egg affords an excellent example of the importance of the nucleus in cell-division. Whenever cells multiply, a division of the nucleus precedes the division of the cell-body. In an insect egg, segmentation begins

by the division of the fertilized nucleus into a number of nuclei, which can be recognised scattered through the yolk before any cell-divisions are apparent. Each nucleus is surrounded by a star-shaped mass of protoplasm; these masses being connected with each other by a network of very fine fibres. The nuclei move towards the margin of the egg (fig. 57, *C*, *D*, *n*), where they arrange themselves in a layer surrounding the yolk; their masses of protoplasm become marked off into distinct cells, and a cell-layer, the germ-skin or *blastoderm* (fig. 57, *E*), is thus formed internal to

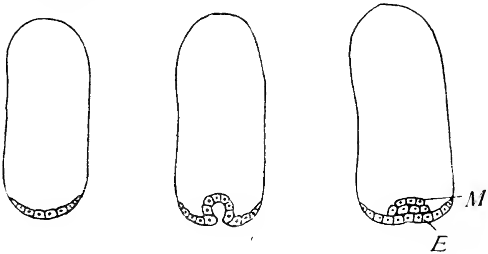


FIG. 58.—Diagram showing formation of germinal layers. *E.* ectoderm; *M.* inner layer. Magnified. From Nussbaum, in Miall & Denny's "Cockroach."

the yolk-membrane. The stage of development now reached, a hollow bag with cellular envelope is known as the *blastula*.

Germinal Layers.—The formation of the embryo begins in an elongate, thickened region of the blastoderm, the *primitive streak*, which extends along the ventral face of the egg. A groove forms along the centre of the primitive streak resulting in a lengthened inpushing (*invagination*) of the blastoderm, which thus becomes two-layered; the surface cells overgrow the open edges of the groove, forming an

outer layer (*ectoderm*), while the invaginated cells spread out to form an inner layer (*endoblast*) (fig. 58). This stage is called the *gastrula*, and is of great importance, as it recalls the structure of the most primitive group of complex animals—the hydroids and corals (Coelenterates) which exhibit throughout life the simple plan of a hollow sac whose wall consists of two cellular layers.

Embryonic Membranes.—Around the edge of

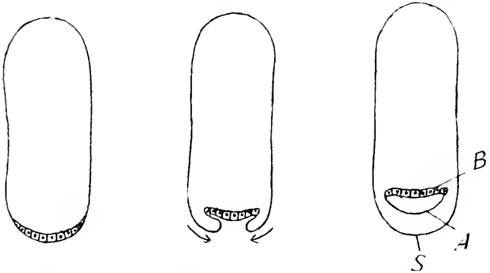


FIG. 59.—Diagram showing formation of embryonic membranes. *A*. amnion; *S*. serosa; *B*. blastoderm. Magnified. From Nussbaum, in Miall & Denny's "Cockroach."

the primitive streak, the ordinary, unthickened blastoderm becomes raised in a double fold. This fold grows over the surface of the primitive streak until its converging edges meet. Its outer layer and its inner layer each become continuous, so that the developing embryo, now sunk into the yolk, is protected by two membranes internal to the yolk-membrane. The outer of these (continuous with the blastoderm) is known as the *serosa*, the inner (continuous with the ectoderm of the primitive streak) as the *amnion* (fig. 59). But in some insects—Dragonflies, Grasshoppers, Moths, some Beetles, and Bugs—there is an inpushing

of the primitive streak into the egg, the necessarily simultaneous inpushing of the adjoining blastoderm forming the amnion (53). The developing embryo is thus transferred to the dorsal face of the egg (fig. 60 *A*, *B*) while the edges of the blastoderm reunite around the invagination. In the eggs of these insects, as growth proceeds farther, the embryo turns in the egg and reverts to its original position on the ventral face (fig. 60 *C*). In the long-horned Grasshoppers, another membrane is formed between the serosa and the amnion. This is the *indusium* (fig 60 *in*), which arises

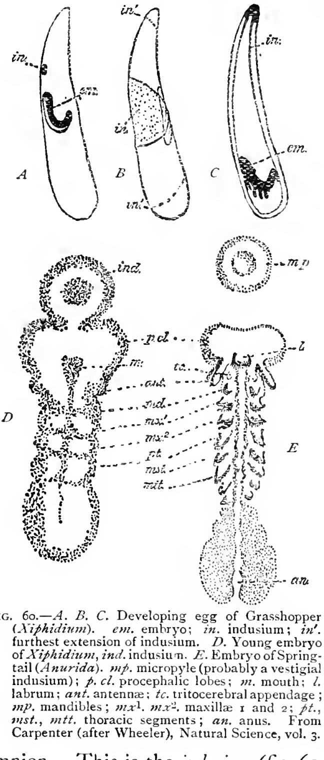


FIG. 60.—*A. B. C.* Developing egg of Grasshopper (*Xiphidium*). *em.* embryo; *in.* indusium; *in'.* furthest extension of indusium. *D.* Young embryo of *Xiphidium*, *ind.* indusium. *E.* Embryo of Springtail (*Anurida*). *mp.* micropyle (probably a vestigial indusium); *p. cl.* procephalic lobes; *m.* mouth; *l.* labrum; *ant.* antennæ; *tc.* tritocerebral appendage; *mp.* mandibles; *mx*[1]. *mx*[2]. maxillæ 1 and 2; *pt.*, *mst.*, *mtt.* thoracic segments; *an.* anus. From Carpenter (after Wheeler), Natural Science, vol. 3.

as a circular thickening of the blastoderm in front of the head region of the embryo, and grows over the egg, covering its whole surface except the poles, and then shrinks again as the embryo increases in size. In the embryos of Springtails and of some flies, the amnion and serosa are not formed at all, or are represented only by vestigial folds (53, 58 b, 64).

Segmentation.—That the primitive streak is destined to develop into an insect is shown at an early stage by the appearance of transverse furrows which divide it into segments, the segmentation beginning at the front end where the primitive band spreads out on either side to form the rounded head-lobes. Between these a central inpushing of the ectoderm marks the position of the future mouth, and ultimately gives rise to the fore-gut (the gullet, crop and gizzard of the insect). A similar central inpushing of the ectoderm at the hinder end of the primitive streak forms the rudiment of the hind-gut. The number of segments varies as observed in different insect embryos, but the normal number may be regarded as twenty-one, of which six belong to the head, three to the thorax and twelve to the abdomen. On each segment, except the first and last, a pair of tiny limbs or appendages bud out. The segments of the head are (1) the head-lobes (*protocerebral* segment) situated in front of the mouth; (2) the antennal (*deutocerebral*) segment whose appendages develop into the feelers, appearing first behind the mouth but moving in front of it as growth proceeds; (3) the intercalary (*tritocerebral*) segment, whose appendages have only been observed in a few embryos and disappear at an early stage; (4, 5, 6) the mandibular and two maxillary segments whose appendages form the three pairs of jaws of the adult insect (fig. 60 *D*, *E*). The three thoracic segments are more or less

clearly discernible in the adult, and their appendages develop into the six legs. A variable number of the hinder abdominal segments become fused together or suppressed in the adult insect, while in no insect, after hatching, except certain Bristle-tails, are all the abdominal limbs present, though those of the ninth and eleventh segments (59) may persist as stylets and cercopods respectively; while in the immature stages of moths and sawflies, as many as eight pairs may be functional as "pro-legs."

The segmentation of the embryo is of great interest because it is believed to give some clue to the nature of the remote ancestors of insects. We see that every insect passes through a stage showing a number of similar segments with similar rudimentary limbs, some of which ultimately become transformed into feelers, others into jaws, others into legs, and others into cercopods. This fact suggests that from ancestors with numerous similar segments, perhaps distantly resembling centipedes, all insects have been developed, the segments of the different regions of the body and their limbs having become modified in different ways for the performance of special functions.

Air-tubes.—The breathing-tubes, like the fore and hind-gut, are formed by inpushings of the ectoderm (fig. 62 *s*). These arise in close association with the developing appendages, the pits which mark the future spiracles appearing shortly after the budding limbs. As development proceeds, these pits lengthen into tubes, which by repeated branching gradually assume the complicated arrangement found in the insect after hatching.

Nervous System.—The nervous system of all animals is developed from the outer skin or ectoderm of the embryo. In insects a median groove is formed

along the primitive streak, and the two main nerve-cords arise in the thickened ectoderm on either side of this groove (fig. 61 *N*). A pair of swellings in each segment develop into the nerve-centres of the

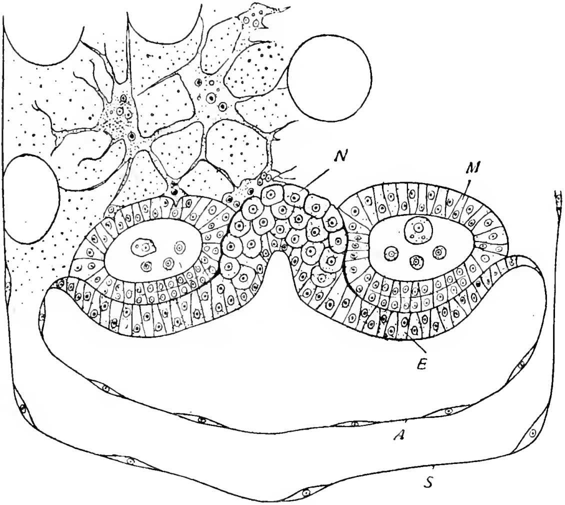


FIG. 61.—Cross section of embryo of German Cockroach. *S.* serosa; *A.* amnion; *E.* ectoderm; *N.* rudiment of nerve-cord; *M.* mesodermal pouches. Magnified 500 times. From Nussbaum in Miall & Denny.

ventral chain, those of the head lobes forming the rudiments of the brain. The special sense-organs are all due to the modification of ectoderm cells. The simple eye of an insect arises as a cup-shaped inpushing of the ectoderm; the invaginated cells lengthen and become changed into the retinal elements

which are overgrown by the outer skin, ultimately modified into the lens. The nerve-centres and cords which lie above the gullet and crop arise as an outgrowth from the wall of the fore-gut (53).

Fore and Hind-gut.—As mentioned above, the fore and hind guts, which give rise to the greater part of the food-canal, are inpushings of the ectoderm. The fore-gut (*stomodæum*) usually appears earlier than the hind-gut (*proctodæum*). The kidney-tubes arise as outgrowths from the latter. The spittle-glands are developed from inpushings of the ectoderm of the head region, similar to the rudiments of the air-tubes. As growth proceeds, these inpushings, originally opening to the outer surface of the blastoderm, become drawn into the mouth-cavity (2, 53).

Dorsal Closure.—It is evident that the primitive streak with the nerve-cord developing along its central line, and the limbs arising from its outer surface, marks the lower or ventral aspect of the future insect. At its first formation it occupies but a small part of the outer area of the egg, but as growth proceeds it elongates and widens. That the body of the future insect may be completed, the back or dorsal aspect must be formed by the extension of the embryo so as to completely enclose the yolk. This process differs considerably in various insects. In some cases (Dragon-flies) there is between the amnion and the serosa behind the head an inpushing of thickened cells, which ultimately form the dorsal body-wall. Or the amnion may, as in some Beetles, become ruptured and turned back from covering the primitive streak until it encloses the yolk dorsally, being finally absorbed as the primitive streak itself spreads to form the dorsal wall. Or, as in some Midges and Caddis-flies, a similar operation may be carried out with the serosa. Or, as in Moths and

Sawflies, there may be no rupture of the membranes, but a backward growth of both primitive streak and amnion around the yolk until the latter is enclosed by the ectoderm, which is then itself completely enveloped by the amnion (**2**, **53**).

In describing many of the organs of the adult insect —the air-tubes, fore-gut and hind-gut for example— it was stated that these are inpushings of the outer skin. We now see that this is no mere figure of speech, but the expression of the simple fact that these organs, though internal in the developed insect, all arise from the outer skin or ectoderm of the embryo.

Endoderm.—The inner-cell layer of the primitive streak must now be considered. As already stated, it is due to the inpushing of the primitive groove sinking a mass of cells under the ectoderm, beneath which they spread to form a primitive inner layer (*endoblast*). Thence are developed the inner and middle embryonic cell-layers—the *endoderm* and the *mesoderm*. The endoderm arises from two cell-masses situated at either end of the embryo in the neighbourhood of the fore-gut and the hind-gut.[1]

Mid-gut.—These cell-masses grow respectively backwards and forwards and become tubular, uniting to form the mid-gut (*mesenteron*), which ultimately opens into the fore- and hind-guts. Thus the food-canal of the insect is completed. In some cases (Bees) the hind-gut remains shut off from the mid-gut during the early stages after hatching.

Mesoderm and Coelom.—The rest of the primitive inner layer forms the mesoderm, from which arise the blood-system, muscles, and reproductive organs. By division of the mesoderm into two layers paired

[1] The three embryonic layers, ectoderm, mesoderm, and endoderm, are often known as *epiblast*, *mesoblast*, and *hypoblast*.

cavities (fig. 61 *M*) are formed in each segment; these are the coelomic pouches, and in most animals (Vertebrates for instance) the body cavity of the adult is formed by the extension and fusion of these primitive pouches. Such a body-cavity is a true *coelom*. In Arthropods and Molluscs, however, the coelom becomes much reduced as growth proceeds (60, 61).

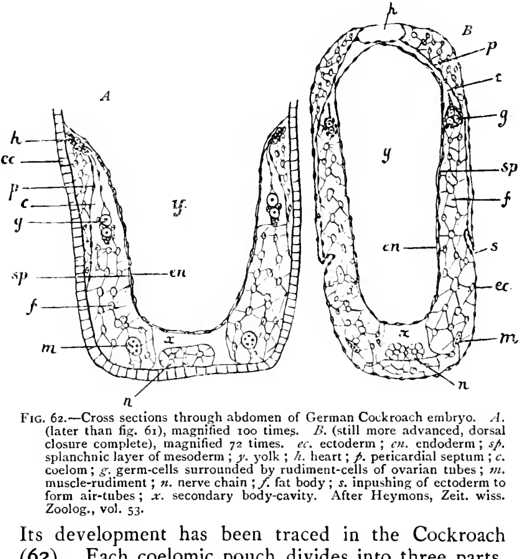


FIG. 62.—Cross sections through abdomen of German Cockroach embryo. *A*. (later than fig. 61), magnified 100 times. *B*. (still more advanced, dorsal closure complete), magnified 72 times. *ec*. ectoderm; *en*. endoderm; *sp*. splanchnic layer of mesoderm; *y*. yolk; *h*. heart; *p*. pericardial septum; *c*. coelom; *g*. germ-cells surrounded by rudiment-cells of ovarian tubes; *m*. muscle-rudiment; *n*. nerve chain; *f*. fat body; *s*. inpushing of ectoderm to form air-tubes; *x*. secondary body-cavity. After Heymons, Zeit. wiss. Zoolog., vol. 53.

Its development has been traced in the Cockroach (62). Each coelomic pouch divides into three parts, of which the dorsal contains the rudiments of the genital organs, the central disappears, and the ventral loses its boundaries as it becomes filled with the

growing fat-body, by whose splitting up the body-cavity of the adult insect is formed (fig. 62 *c*, *f*).

Blood-system.—The heart, blood-spaces, and fat-body arise by modification of the cells of the mesoderm. The rudiments of the heart are rows of cells which lie within either edge of the primitive streak (fig. 62 *h*). As the yolk is enclosed, these rudiments take up a more dorsal position until they join along the upper middle line forming the heart and pericardium (fig. 62) (**53**).

Reproductive Organs.—The development of the ovaries has been carefully traced in the Cockroach (**63**). At a very early stage, before segmentation begins, the primitive germ-cells can be recognised; they arise at the hinder end of the mesoderm, from the ordinary cells of which they may be distinguished by their larger size. As the embryo segments, and the coelomic pouches appear, further germ-cells are developed from their walls, and take up a dorsal position in the coelomic cavities, where they become surrounded with other mesodermal cells, which arrange themselves to form the oviduct and ovarian tubes and threads. Throughout the development the germ-cells, which are to become eggs, are quite distinct from the cells which give rise to the tissues of the ovary (fig. 62). The organs of the male insect are developed in a similar way, the germ-cells which produce the sperm-cells being all along distinct from the cells which give rise to the tissues of the testes and their ducts. A point of great interest is the separation, in the male cockroach, from the developing testes, of a remnant which represents the female part of an originally bisexual state, since it occasionally gives rise to a rudimentary ovary with eggs (**63 b**).

The outer genital passages—vagina of the female and ejaculatory duct of the male—are formed, like

the air-tubes, by inpushings of the ectoderm, which meet and unite with the internal, mesodermal ducts.

Polar Cells.—In some Flies and Midges the rudiments of the germ-cells have been traced yet further back. While the primitive cell-segmentation is still in progress, before the formation of the inner layer, a "polar cell"[1] is separated from the hinder pole of the egg. This by successive halving divides into eight cells, which, after the formation of the blastoderm, pass through it, and divide into two groups, taking up positions on either side of the hind-gut. From these cells the eggs or sperm-cells of the developing insect arise (65). This very early separation of the primitive germ-cells is of great interest, as it lends support to the well-known theory of Weismann (57) that, in all animals, the nuclear matter (germ-plasm), which passes on the inherited characters of the race from generation to generation, is distinct from the nuclear matter whose division gives rise to the body of the individual. It is thought by those who hold this view that in all cases the primitive germ-cells are distinct from the ordinary cells of the embryo, though only a few instances are known in which this distinction is clearly marked and capable of being observed.

Hatching.—The time occupied by development within the egg varies from less than a day in the Blow-fly to nine months in many insects, Locusts, Moths, etc.,—whose eggs, laid in summer, do not hatch out till the next spring. Some insects, after hatching, undergo a great change in form. The embryo Cockroach, for instance, is three times as deep as wide, but soon after its escape from the egg-membrane these proportions become reversed, and the

[1] It is important that these cells should not be confused with the polar bodies or directive corpuscles described above (p. 86).

young insect is three times as wide as deep, having already assumed the flattened form of body which adapts cockroaches to life in concealed situations. In some Grasshoppers the vestigial limbs on the first abdominal segment are not lost until hatching-time. In Earwigs, some Beetles, Lacewing flies and Fleas, one or more sharp points or cutting-edges, "hatching-spines," are developed on the head of the embryo; by means of these the egg-shell is pierced. After leaving the egg-shell, the embryo has to cast off the amnion before hatching is complete. This process has been observed in an American locust, which, by inflating the loose skin between its head and thorax, bursts the amnion, and then slips it over the head, withdrawing first the feelers and legs, then the hind-body, and finally the hind feet. Kicking away the now discarded membrane with these, the newly-hatched locust walks away (66).

In the vast majority of insects the development of the egg takes place for the most part, after it has been laid by the mother. In some cases, however, the egg is hatched within the body of the parent, and the young insect is born in an active state. The Plant-lice furnish the most familiar example of this "viviparous" reproduction, which also occurs in some May-flies, two-winged Flies and a few Beetles.

Young Insects and their Growth.—In the more primitive insects, the newly-hatched young is a miniature reproduction of its parent. A young Springtail or Cockroach (see fig. 1 *d*) is at once recognised as such, though the wings of the latter are not fully developed until the final moult, as is the case with all winged insects. The newly-hatched Grasshopper or Locust (fig. 63 *a*) has no wings, but it shows from its earliest days the long leaping hind-legs of its parent. In the course of growth, repeated moults, or

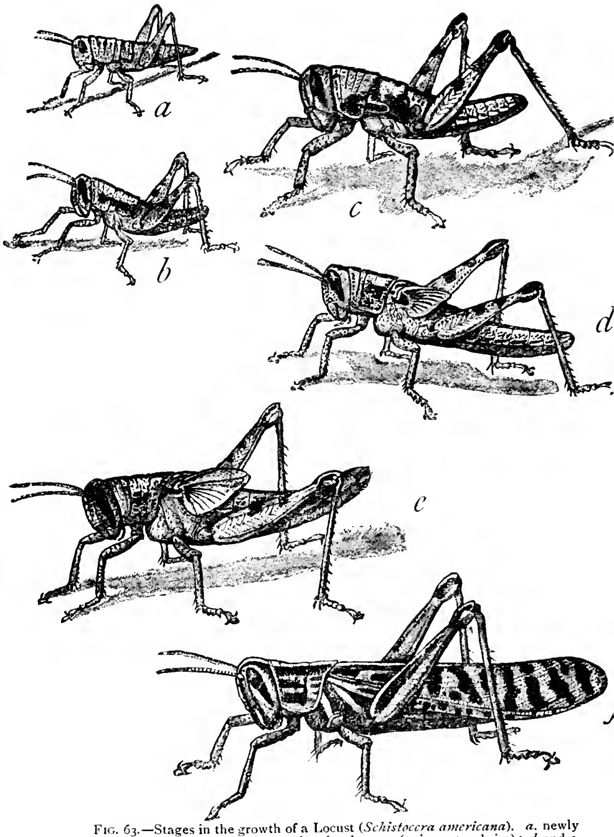


FIG. 63.—Stages in the growth of a Locust (*Schistocera americana*). *a.* newly hatched (magnified); *b. c.* 2nd and 3rd stages (twice natural size); *d.* and *e.* 4th and 5th stages (natural size); *f.* adult (natural size). From Howard, Insect Life, vol. 7 (U.S. Dept. Agr.).

skin-castings, are undergone, and in the third stage (fig. 63 *c*) the wing-rudiments are clearly visible as outgrowths from the second and third fore-body segments. In the fourth and fifth stages (fig. 63 *d*, *e*) these rudiments are conspicuous, and show plainly the radiating nervures. A short time after the fifth moult, the wings spread and harden, and the Locust assumes the adult form (fig. 63 *f*).

Forms of Larvæ.—Most insects, however, in the first period of life after hatching, differ markedly from their parents in form, structure and habits. From the egg of a Moth hatches out a creeping Caterpillar, from that of a Fly a sluggish Maggot. An animal in its early stage thus differing from its parents is known as a *larva*, and the term is often applied to insects generally as hatched from the egg, though it should not be given to those which differ from their parents only in size and in the absence of wings; for such the term *nymph* is preferable (2). Insect larvæ show the greatest variation in their form and structure. Most of them may, however, be referred to one of two types.

Campodeiform Larvæ.—As an example of the first type we may take the grub of a Ground-beetle. It is an elongate, active creature, with a broad, quadrate head, three thoracic segments, corresponding to those of the perfect insect and bearing each a pair of legs and ten visible abdominal segments (fig. 64). The segments of the thorax have the skin almost completely chitinised. Each segment of the hind-body has a single strong chitinous tergal plate, a pair of pleural plates, and (as regards the first seven segments) seven ventral or sternal plates. The eighth segment has but three ventral plates and the ninth only one, while the tenth segment is a truncated "anal cylinder" (fig. 64,[10]). The head bears append-

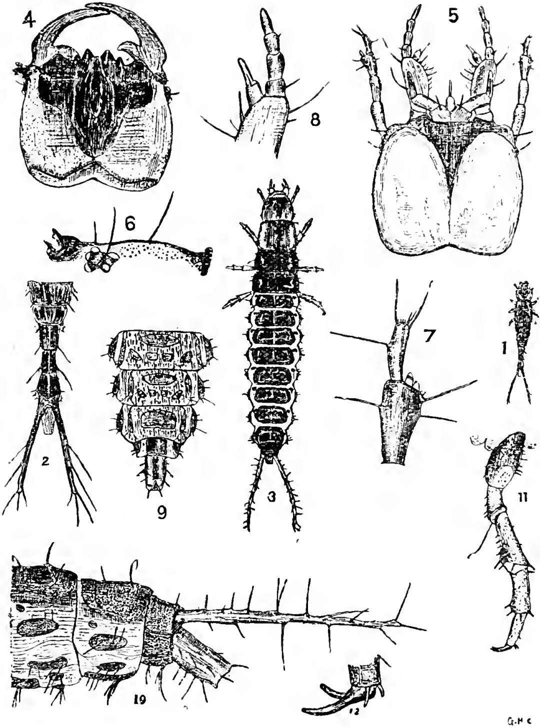


FIG. 64.—Larva of Ground-beetle (*Pelophila*). 1. Young larva; 2. its hinder segments; 3. full-grown larva; 4. head from above; 5. from beneath showing feelers and maxillæ; 6. from side showing ocelli; 7. terminal segments of feeler; 8. tip of first maxilla; 9. hinder abdominal segments from beneath; 10. from side; 11. a leg of the first pair; 12. end of foot. Nos. 1 and 3 are enlarged 3 times, the others more highly magnified. From Johnson & Carpenter, Trans. Ent. Soc., 1898.

ages corresponding with those of the perfect insect, but in a much more primitive condition. Each feeler has but four segments, the third carries, alongside the fourth, a small papilla which shows traces of segmentation, and suggests that the feeler was primitively branched (fig. 64,7). The mandibles are powerful, but each carries only a single stout tooth in place of the complex serrate cutting-edge presented by the mandible of the adult. Each maxilla of the first pair consists of a long basal segment (stipes), on which are placed the blade (lacinia) represented only by a tiny tubercle with a bristle, the hood (galea) consisting of two short cylindrical segments and the palp with three segments springing from a short palpiger (fig. 64,[8]). As in the adult, the second pair of maxillæ are joined to form a lower lip, but each palp has only two segments. A striking difference between the head of this larvæ and that of the beetle into which it will grow is presented by the eyes. No compound eyes are present in the grub; only a group of six simple eyes (ocelli) can be distinguished behind the base of each feeler (fig. 64,[6]). The legs of the grub are much shorter than those of the perfect insect; the haunch, trochanter, thigh and shin can be easily recognised, but the foot consists of only one segment (fig. 64,[11]). At the tail-end of the hind-body is a pair of long cercopods covered with many nodules and stiff bristles (fig. 64,[10]).

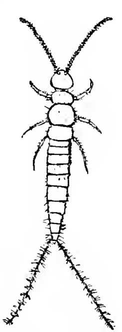


Fig. 65.—Campodea. Magnified 4 times.

Such a six-legged, active grub is known as a *campodeiform larva*, on account of its general likeness to the bristle-tail Campodea, a small wingless

insect with a pair of long-tail cercopods (fig. 65). Very many insects develop from campodeiform larvæ; the grubs of numerous Beetles, of Stoneflies, Mayflies, Dragonflies and Lacewing flies all belong to this type (67, 68).

Eruciform Larvæ.—No better example of the second type of larva can be found than the caterpillar of a Moth (fig. 66). In many respects it contrasts strongly with the armoured, active, six-legged beetle-grub. Except for the large head which is completely chitinised, the short legs, and some hooklets, tubercles, or spines, the whole of the cylindrical worm-like body is soft-skinned. As in the beetle-grub, simple eyes only are present, and the feelers

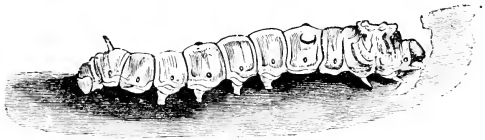


FIG. 66.—The Common Silkworm or Caterpillar of the Moth *Bombyx mori*. Natural size. From Riley, Bull. 9. Div. Ent. U.S. Dept. Agr.

are very short. The head bears a pair of powerful mandibles, by means of which the caterpillar devours leaves; in the moth it will be remembered these jaws are reduced to the merest vestiges. The maxillæ of the first pair (which form the long sucking-trunk of the moth) are, in the caterpillar, small and inconspicuous organs; each consists of a basal plate bearing two short, segmented processes—the hood and the palp. The maxillæ of the second pair are fused together to form a plate-like lower lip, and the tongue projects as a tubular spinneret through which open the ducts of the silk-glands (fig. 67). These glands are long paired tubes,

often much longer than the body of the larva wherein they lie folded. They secrete a sticky fluid, which, after pressure in the spinneret, is forced out through the duct as a double, flattened thread of silk. Each of the three thoracic segments bears a pair of short legs with hard chitinous feet and claws; these legs correspond, of course, with those of the perfect insect, from which, however, they differ immensely in form. The first, second, seventh and eighth abdominal segments are limbless, but the third, fourth, fifth, sixth, and ninth each carry a pair of short, stumpy "prolegs"—cylindrical in shape and armed at the tips with incomplete circles of hooklets. Clasping the twig on which it rests with its prolegs, the caterpillar stretches out the front part of its body and grasps, with its thoracic legs, a point further in advance. Then the prolegs disengage their clasp; by contraction of the body lengthwise they are drawn forwards to seize the twig again at a point nearer that where the thoracic legs are holding. Thus by successive stretching and shrinking of its body, brought about by the action of longitudinal bands of muscles in each segment, the caterpillar goes on its way in search of food.

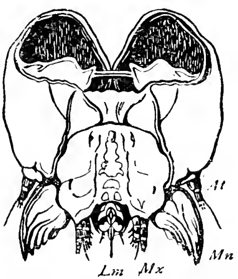


FIG. 67.—Head of Goat-moth Caterpillar (*Cossus*) from behind. Magnified. *At.* feeler; *Mn.* mandible; *Mx.* 1st maxillæ; *Lm.* 2nd maxillæ with spinneret. After Lyonnet, from Miall & Denny.

Such a soft-skinned, worm-like grub is known as an *eruciform larva*, and this type prevails among the most highly developed insects—the Moths, Flies, Ants and Bees for example. Very considerable modifica-

tion, however, can be traced in the structure of different eruciform larvæ. The grubs of most Saw-flies are caterpillars like those of moths, but there are from six to eight pairs of prolegs present; in moth-caterpillars there are hardly ever more than five pairs, while in some cases there are only two pairs, those on the sixth and ninth segments of the hind-body. In the grubs of Flies, legs like the thoracic limbs of the caterpillar are entirely wanting. In some cases—the "rat-tailed grub" of the Drone-fly for example—the insect crawls by means of seven pairs of circular sucker-feet, provided with hooklets like those of the caterpillar's prolegs. Or all traces of limbs of any kind may disappear and the grub become a *maggot*, like the offspring of the House-fly (fig. 68)

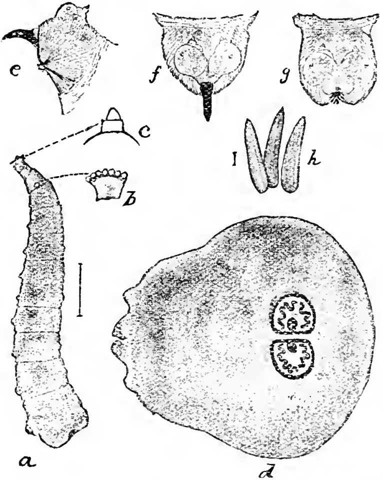


FIG. 68.—*a*. Full-grown Maggot of Housefly (*Musca domestica*), magnified 5 times; *b*. fan-shaped closed spiracle on first body-segment; *c*. head-region protruded; *d*. tail-segment showing functional spiracles; *e*. head-region from side; *f*. from above showing hook-jaws; *g*. head of young maggot, from above; *h*. egg. *b.*—*h*. more highly magnified. From Howard, Bull. 4 (n.s.) Div. Ent. U.S. Dept. Agr.

or the Bees. The bodies of maggots are highly contractile; the head can be drawn far back within the body. In the most degraded types a definite chitinised head capsule is no longer to be found, and the head is merely a fleshy, protrusible "proboscis" armed with hook-like jaws (fig. 68 *e*, *f*). The caterpillar, living openly on leaves, breathes through nine pairs of spiracles (fig. 66), one prothoracic and eight abdominal pairs. But the fly-maggot, buried in dung, breathes only through a pair of large spiracles on the hindmost

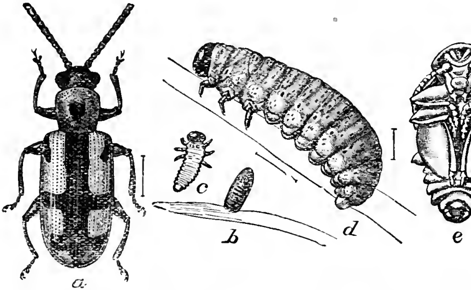


FIG. 69.—*a*. Leaf-beetle (*Crioceris asparagi*); *b*. egg; *c*. young larva; *d*. full-grown larva; *e*. pupa. Magnified 5 times. From Chittenden, Yearbook, U.S. Dept. Agr., 1896.

segment (fig. 68 *d*). A pair of projecting, fan-shaped spiracles, on the thorax (fig. 68 *b*) are closed up and useless (4).

Transition between Larval Types.—The distinction between the campodeiform and eruciform types of larvæ, though convenient, cannot be rigidly maintained. Among the Beetles (2, 136) an almost complete transition can be traced from the one to the other. The grub of a Ground-beetle (as described above) or of a Rove-beetle is an active, six-legged

creature, covered with an armour of chitinous plates and sometimes provided with a pair of long tail cercopods. The grub of a Click-beetle is a narrowly cylindrical or flattened worm-like insect (commonly known as a "wireworm") with the segments of the body well chitinised, but with the legs very short, and the cercopods reduced to short processes or altogether wanting (fig. 121). The larva of a Leaf-beetle (fig. 69) is a thick, soft, fleshy grub, swollen at the hinder end, the only parts with chitinised skin being the head and the short legs. The grub of a Pea-beetle (fig. 70) has a small hard head and large soft white body, while the legs are usually absent.

Hypermetamorphosis.—It is yet more interesting and suggestive to find both forms of larva in the life-history of the same insect. The young of an Oil-beetle when first hatched is a tiny campodeiform larva. It lives an active life on plants until it attaches itself to a bee, which carries it to her nest, where it feeds on her eggs. After casting its skin it becomes a soft, short-legged grub; in this stage its food consists of the honey stored by the bees. Another change of skin leads to a third stage in which no food is taken, the jaws being immovable and the legs reduced to tubercles. A third moult is succeeded by the fourth and final larval condition, the Oil-beetle grub

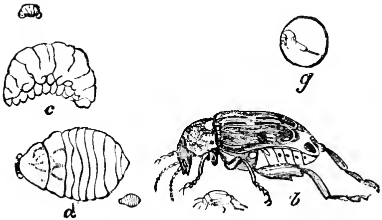


FIG. 70.—*b.* Pea-beetle (*Branchus pisi*); *c.* larva; *d.* pupa; *g.* pea with hollow eaten by larva. Magnified 5 times. From Riley (after Curtis), Insect Life, vol. 4 (U.S. Dept. Agric.).

being now a legless maggot, resembling in its appearance those of the bees and feeding on honey. Insects which pass through such a succession of larval forms are said to undergo *hypermetamorphosis*. The fact that in such insects the campodeiform precedes the eruciform type of larva, seems to indicate that the former is the more primitive, and that the latter has been assumed together with a sluggish habit of life. The newly hatched grub of a Pea-beetle differs from the older larva in possessing three pairs of short legs. By means of these, assisted also by cutting-spines on the prothorax, it is enabled to make its way through from the egg laid outside the pod to the enclosed pea wherein its development is completed, and where it assumes the form of a legless maggot (fig. 70 *c*). In the vast majority of cases, the conditions suitable to the eruciform type surround the larva from the time of its hatching, and the campodeiform stage is naturally suppressed. But its retention in the few instances where the individual insect has to undergo changed conditions of life during its development gives us a hint as to what must have taken place in the course of the evolution of the insect races (67, 68, 70).

Adaptation of Larvæ.—The form of any larva indeed can be seen to be adaptive to its manner of life. Larvæ, like those of the ground-beetles which live by preying upon other weaker creatures, are necessarily active and protected by a hardened skin. Grubs which live an underground life or bore in the wood of plants, and are therefore to a great extent protected, are soft-bodied, though in order that they may be able to feed on the firm vegetable tissues, their head-capsules are hard and their mandibles well developed. The narrow, pointed, hardened body of the wireworm enables the creature to bore its way

through the soil in search of food. The presence of an abundant food supply obtainable without exertion is always correlated with the degraded form of larva to which the term "maggot" is applied—no feet, and often no chitinised head-capsule with its special sense organs. Such maggots are the offspring of insects which lay their eggs in a mass of food-material, as the Blowfly, or which carefully tend and feed their young, as the Wasps. In the case of a few degraded parasitic flies, the whole larval life is passed within the body of the mother, and the insect is only born in the stage preceding the perfect condition (67, 71, 72).

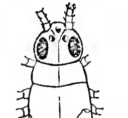


FIG. 71.—Nymph of May-fly (*Chloeon dipterum*), with wing-rudiments (*a*) and tracheal gill-plates (*b. b.*). Magnified 7 times. From Miall & Denny (after Vayssière). [The feelers and legs are cut short.]

Aquatic Larvæ.—In a large number of insects the larval and nymphal stages are spent in the water. Aquatic larvæ, like those which live on the land or burrow in the soil, may be vegetarians, flesh-eaters or scavengers. Their peculiar interest lies in their method of breathing. The usual air-openings (spiracles) are necessarily closed against the ingress of water. Many aquatic grubs breathe the air dissolved in the water by means of leaf-like gills through which run branching air-tubes. Stone-fly and May-fly grubs, for instance, possess pairs of such tracheal gills on several segments of the body (fig. 71). In the Alder-fly grub, the paired tracheal gills are tubular and jointed, and the tenth segment of the hind-body is lengthened out into a fringed "tail,"

which also serves as a breathing-organ. In certain Dragon-fly grubs there are three elongate gills at the

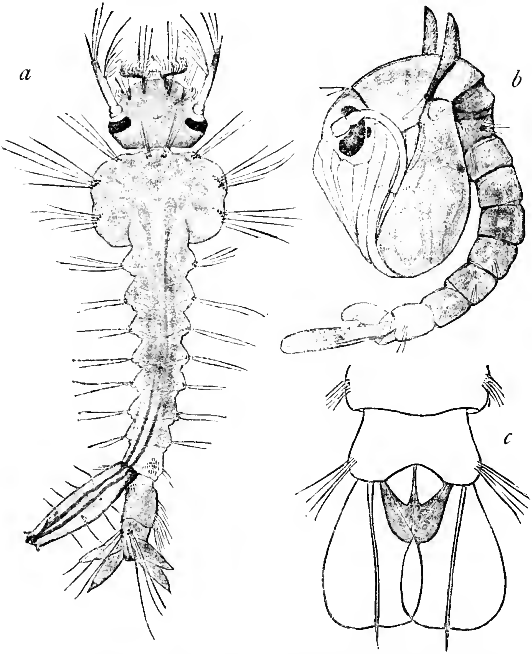


Fig. 72.—*a*. Larva of Gnat (*Culex*); *b*. pupa, magnified 10 times; *c*. tail-segment of pupa, more highly magnified. From Howard, Bull. 4 (n.s.) Div. Ent., U.S. Dept. Agr.

tail end of the abdomen. Other dragon-fly grubs take water into the hind-gut over whose walls run tracheal

tubes capable of absorbing the dissolved air. A very beautiful adaptation seen in many aquatic larvæ—that of the Gnat for instance—is a valve consisting of several leaf-like plates, which close a spiracle at the tail end of the insect (fig. 72 *a*). The points of these valve-plates are capable of piercing the surface-film of the water, and the plates then expand so as to form, in conjunction with the depressed film, a cup containing air and communicating freely with the insect's body as it hangs from the surface, head downwards. Should such a larva have occasion to dive, sufficient

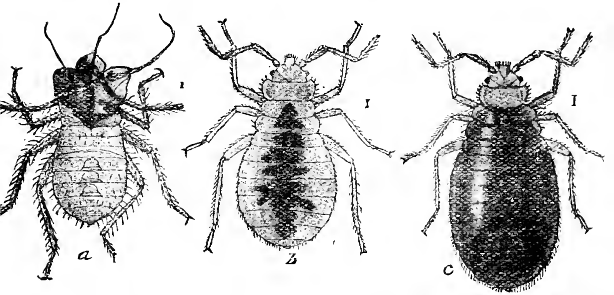


FIG. 73.—*a*. Cast-off first nymphal skin oi Bed-bug (*Cimex lectularius*); *b*. second instar after emergence from *a*.; *c*. the same after a meal. Magnified 30 times. From Marlatt, Bull. 4 (n.s.) Div. Ent. U.S. Dept. Agr.

air can be stored in the body to allow submergence for a considerable time (170).

Moulting.—It is evident that the plan on which insects, as well as all arthropods, are built up—a hard outer skeleton surrounding the muscles and soft organs—necessitates a casting of the skin at successive periods as the creature grows, since the hard, unyielding texture of the chitin forbids expansion, either of itself, or, beyond certain limits, of the contained

organs. Consequently as the newly-hatched nymph or larva develops into the perfect insect, it has to undergo a series of skin-castings or moultings (*ecdysis*). The process begins with a splitting of the skin on the upper surface of the thorax, this is continued forward to the head, which opens along the sutures. The head and thorax of the new stage (*instar*) are then worked out by an energetic wriggling motion of the insect, and the old skin is gradually slipped off from before backwards like the finger of a glove (fig. 73). In caterpillars it is known that a fluid, secreted by glands in the hypodermis, is present at moulting-times between the new and the old skin, which it helps to separate. The head of the new instar in a caterpillar can be seen, before the moult takes place, through the first thoracic segment. It is, of course, larger than the head of the previous instar, and, after moulting, looks disproportionately large as compared with the body. During the succeeding stage, the body grows larger, while the head retains its original size, appearing, when the time for the next moult draws near, disproportionately small (2, 3).

Incomplete and Complete Metamorphosis.—Through such a succession of moults, then, the insect arrives at its adult condition—becomes an *imago*. But the details of the changes undergone vary greatly in different insects. In some cases the insect, throughout its development, is able to move and feed. The grub of a May-fly, for example, after the first few moultings, shows the rudiments of wings in outgrowths from the terga of the second and third thoracic segments. At each successive moult these rudiments become larger, and the nymph, in its final stage (fig. 71 *a*), quits the water ready for the emergence of the fly. This gradual change from the larva to the perfect insect is known as *incomplete metamorphosis*;

the insects which undergo it are said to be *hemimetabolous*. On the other hand the insect, during the stage before the imago, may be passive, resting for the most part in one position and taking no food, as in Moths, Flies, Beetles (fig. 69), and Bees. The insect in this resting-stage is known as a *pupa*, differing markedly in its form both from the larva whence it has grown

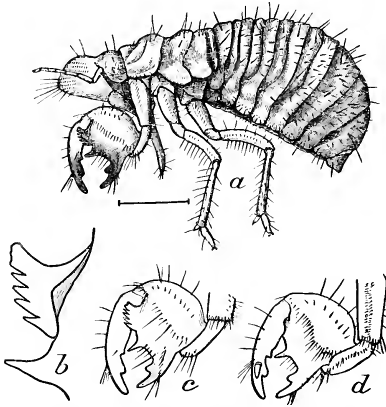


FIG. 74.—*a*. Nymph (4th stage) of Cicad, magnified 5 times; *c*. front leg, inner face; *d*. outer face, magnified 7½ times; *b*. teeth on thigh, more highly magnified. From Marlatt, Bull. 14 (n.s.) Div. Ent. U.S. Dept. Agr.

and from the imago to which it will turn. Insects which pass through a resting pupal stage are said to be *holometabolous*, or to undergo a *complete metamorphosis*.

To a great extent, however, various stages in the degree of metamorphosis can be traced. As previously mentioned, a Cockroach or a Grasshopper, when newly hatched, is a nymph, resembling closely the perfect

insect in form and differing only in the absence of wings. A Dragonfly or a Mayfly begins free life as an aquatic larva, not resembling its parents; after a few moults this becomes a nymph, showing an approach to the body-form of the imago and bearing rudimentary wings. The offspring of a Cicad (see fig. 86) is a burrowing grub (fig. 74), provided with strong, digging fore-legs, and very unlike its parent in appearance. During a long underground life, it undergoes successive moults and obtains the rudiments of wings; during the stage previous to the emergence of the imago it ceases to feed and remains quiescent within an earthen cell (fig. 75), thus showing some approach to the pupal habit though no pupal form is assumed. In the tiny black insects known as Thrips (often found abundantly on flower-heads) the nymph in its last stage, though it moves, is sluggish; its limbs are enveloped in a membrane and its wings enclosed in sheaths. The Scale-insects furnish a specially interesting transition stage. While the females undergo a typically incomplete metamorphosis, the males (see fig. 110) pass the ante-imaginal

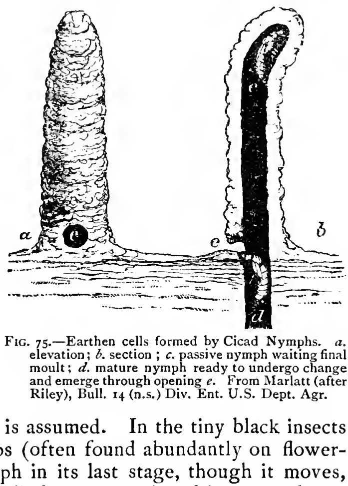


FIG. 75.—Earthen cells formed by Cicad Nymphs. *a.* elevation; *b.* section; *c.* passive nymph waiting final moult; *d.* mature nymph ready to undergo change and emerge through opening *e*. From Marlatt (after Riley), Bull. 14 (n.s.) Div. Ent. U.S. Dept. Agr.

stage in a passive pupa-like condition enclosed in a waxy cocoon (fig. 76). And in the form and habits of pupæ among the insects with complete metamorphosis the greatest divergence can be observed (2, 71, 72).

Forms of Pupæ.—The pupa among Beetles (fig. 69), Lacewing flies and Caddis-flies, Ants, Wasps and Bees for example, shows in many respects the characters of the perfect insect. The appendages of the head and the legs, though lying closely pressed to the body, are free and easily recognisable; the wings, though very small as compared with those of the imago, hang like flaps from the thoracic segments. Such a pupa is distinguished as *free*. Some free pupæ do not remain passive throughout the term of their existence. The pupa of a Gnat, though usually floating passively at the surface of the water, can dive to escape danger. The pupa of a Snake-fly, just before the final moult, regains its activity and runs about; while the Caddis-fly pupa, in preparation for its change into the perfect insect, bites its way out of its sunken protective dwelling-place and swims through the water to escape into the upper air. The pupæ of the more primitive Moths closely resemble those of Caddis-flies. On the other hand, the pupæ of the vast majority of Moths (fig. 77), of Butterflies and of two-winged Flies have the limbs and wings not merely pressed closely to the body, but immovably fixed thereto by a general hardening and fusion of the outer skin. Such pupæ are distinguished as *obtect*.

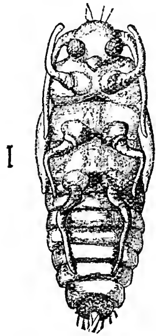


FIG. 76.—Pupa of male Scale-insect (*Icerya*). Magnified 15 times. From Riley, Insect Life, vol. 1 (U.S. Dept. Agr.).

But although the limbs are incapable of motion, certain abdominal segments remain free, so that the hind-body can be, to some extent, bent and turned about. And by means of rows of spines on the abdominal segments, the pupa is, in many cases, enabled to work its way out of its shelter when the time for the final change has arrived. In pupæ with this habit, the fusion of the appendages with the body is less perfect than in those which never move at all; consequently they are often distinguished as incompletely obtect, or "incomplete" pupæ (76, 77).

Fig. 77.—Pupa of Gipsy Moth (*Ocneria dispar.*) between leaves, joined by silken threads. (Below to the left is the cast larval skin). From Riley (after Ratzeburg), Insect Life, vol. 2 (U.S. Dept. Agr.).

Protection for Pupæ.—Insects which pass through a pupal stage are necessarily in a very defenceless condition, and consequently require some kind of protection. The most usual covering for a pupa is a silken *cocoon* which is spun by the larva as its last act before passing into the pupal state (fig. 78). The cocoon is formed of silken threads which are produced by the hardening of the fluid secreted by the long, paired tubular spinning-glands. In some cases the cocoon is simply the lining of an earthen cell, the

larva having passed its life underground or buried itself before pupation. Sometimes foreign matters are worked into the cocoon, as in the case of timber-living larvæ, which strengthen their cocoons with chips of wood; or such material may form the greater part of the cocoon, as in the case of many caterpillars which simply roll leaves and fasten them together with a few threads (fig. 77). The cocoon when completed may contain so much silk, so densely woven as to form a hard shell-like case, as that of an Eggar moth. Many caterpillars are known to secrete acid from a gland opening beneath the prothorax, which renders the silk very firm (78 b); or the cocoon may be a loose meshwork within which the pupa lies, as that of certain Leaf-beetles. In Butterflies it is reduced to a pad of silk, by which the pupa is suspended, with the addition, in some cases, of a single thread engirdling the pupa and affixing it to a support. In the vast majority of two-winged Flies, the last larval skin, instead of being worked off by the usual process, continues to surround the pupa

FIG. 78.—Cocoon surrounding pupa of Silkworm Moth (*Bombyx mori*). From Riley, Bull. 9 Div. Ent. U.S. Dept. Agr.

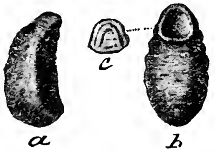


FIG. 79.—Puparium of Warble-fly (*Hypoderma bovis*). *a*. side view; *b*. ventral view showing opening for escape of fly left by rupture of lid *c*. Natural size. From Osborne (after Clark), Bull. 5 (n.s.) Div. Ent. U.S. Dept. Agr.

whence it has separated, and hardening, becomes transformed into a protective pupa-case or *puparium* (fig. 79).

Breathing of the Pupa.—The puparium, however, remains connected with the enclosed pupa by air-tubes, through which breathing can be carried on, and the thoracic spiracles, useless during the larval stage (fig. 68 *b*) now become functional. The devices for enabling insects to breathe during the pupal stage are very varied. Pupæ to which the free air can get access breathe by means of their abdominal spiracles, whether they are suspended in the open or buried in an earthen cell. Pupæ which live submerged in water necessarily have the spiracles closed. Some breathe the dissolved air by means of gill filaments; the aquatic pupæ of Midges are provided with tufted or branching filaments in connection with the air-trunks of the first thoracic segment. Others—those of Gnats for instance (fig. 72 *b*)—breathe through a pair of stout tubes ("respiratory trumpets"), also on the first thoracic segment, the upper extremities of the tubes remaining in contact with the surface film of the water as the pupa floats about (170). Similar respiratory trumpets on one or two segments of the body also serve to convey air to pupæ, like those of many flies, which are buried in mud or foul refuse.

Formation of the Imago.—As those insects which pass gradually from the nymph to the perfect state assume by degrees the wings and other outward characters of the adult, a correspondingly slow and gradual process of change goes on internally, the most important feature being the maturing of the organs of generation. In insects which undergo a complete metamorphosis the reproductive organs also slowly mature through larval and pupal life, while the nervous system becomes gradually modified by

concentration. Many of the organs of the imago in such insects, however, do not arise directly by growth from those of the larva and pupa, but are new structures, developed within the larva from rudiment-groups of cells which are known as "imaginal buds" (fig. 80). From the inner skin of a caterpillar, for example, are produced the buds which will develop into the wings and legs of the Butterfly. The head of a Midge or a Fly, with the eyes, feelers, and jaws are developed in an inpushing of the skin reaching back into the thorax of the larva (fig. 81). The food-canal, glands, and air-tubes of a Moth or a Bee spring from imaginal buds. Just before and during the pupal stage the organs, as they existed in the larva, become dissolved, their component cells breaking down and being absorbed by the blood corpuscles. This degenerative process is known as *histolysis*. Meanwhile from the imaginal buds the organs of the perfect insect are built up, the energy required being drawn from the stored-up food-material in the blood and fat-body (2, 4, 57 c, 73, 74).

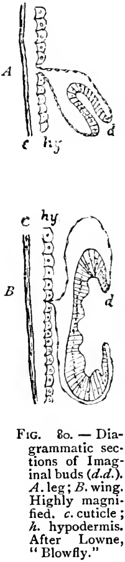


FIG. 80. — Diagrammatic sections of Imaginal buds (*d.d.*). *A*. leg; *B*. wing. Highly magnified. *c*. cuticle; *h*. hypodermis. After Lowne, "Blowfly."

Emergence of the Imago.—When the adult organs are fully developed, the pupa-skin separates from the underlying tissues as the successive larval skins have done, and splits open in the thoracic region to allow the escape of the imago. The emergence must be regarded as the last of the series of moults undergone by the insect in the course of its growth. The skin of the new-born imago, when it first comes out of the pupa-skin, is soft, but it quickly hardens on exposure to

the air. A very important change which must take place in the perfect insect after emergence is the growth of the wings. These organs during the stage just finished have been confined within the narrow limits of the wing-rudiments of the pupa or nymph. Quickly after emergence, therefore, the insect makes its way to a place where the wings will have space to attain their full size. A newly-emerged Moth, for instance, usually climbs to some twig where it can rest with the wings hanging downwards. Blood and air flow into the wing-nervures, and the organs of flight, at first crumpled and soft, soon assume their proper size and firmness.

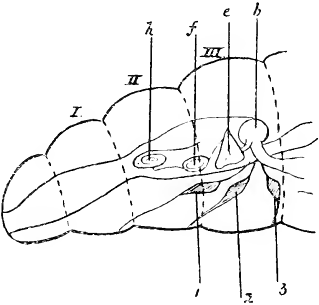


FIG. 81.—Diagram showing position of imaginal buds in larva of Fly. I. II. III. the three thoracic segments of the larva; 1. 2. 3. buds of the legs of the imago; *h.* bud of head-lobes; *f.* of feeler; *e.* of eye; *b.* brain. Adapted from Korschelt and Heider, and Lowne.

Various devices are necessary to enable insects, emerging from pupæ in enclosed spaces, to reach the outer air. The caterpillars of certain Moths feed within the wood of trees, and the pupæ lie concealed in the gallery bored in the trunk or branch. The pupa is provided with rows of spines on the segments of the hind-body, and several of these segments being capable of motion, the creature is able to work its way out of the burrow and protrude its head and fore-body into the free air (77). Pupæ which remain

buried underground—those of Crane-flies for example—work their way to the surface and raise themselves half out of the soil before the fly emerges. The pupæ of Caddis-flies and of the most primitive Moths bite an opening out of their cocoons by means of powerful mandibles. Some Moths enclosed in a very firm and dense cocoon, secrete from the hind-gut a solvent which weakens the cocoon sufficiently to allow the insect to break its way out (78 a). The pupa of the Gnat lives in water, but floats with the thorax just beneath the surface, so that the imago can emerge directly into the upper air. Pupæ of certain midges (*Simulium*), on the other hand, live in cocoons attached to stones or to the stems of water plants; the imagos, on emerging from these, rise to the surface enclosed in a bubble of air, the air having been absorbed from the water by the gill-filaments of the pupa and allowed to accumulate beneath the skin (170).

Sub-imago.—Insects, as a rule, undergo no further moult after attaining the winged state. Mayflies, however, furnish an exception. After a long larval and nymphal life passed in the water and lasting several years, the winged insect appears as a *sub-imago*, which quickly casts a delicate skin revealing the true imago. The sub-imago of the Mayfly is comparable to the pupa of insects with a complete metamorphosis, and very possibly represents the survival of a moult during the winged state which was originally universal among insects.

"Division of Labour" between Larva and Imago.—While the larva and nymphal life of the Mayfly lasts for several years, the imago survives but a few hours, or at most a few days; the shortness of these insects' lives in the winged state has passed into a proverb, and their name is associated with all that

vanishes quickly away. They furnish an extreme illustration of that "division of labour" between the larval and perfect stages to be observed, more or less, in all insects which undergo a metamorphosis. An animal has both to feed that it may live its own life, and to leave behind it offspring to continue the life of the race. Among insects these two functions —feeding and reproduction—tend to become divided between the stages of the life-history. The great business of a larva is to take in food so as to store up a supply of material whence the parts of the imago can be built up; its organs of generation being undeveloped it is incapable of propagating the race. But the principal function of the perfect insect is not feeding but breeding. The ovaries of the female are often so large that the hind-body seems full of eggs. The male is provided with elaborate sense-organs, enabling him to discover the female, often also with scent- and sound-producing structures to allure her when discovered. Everything is adapted to secure a speedy pairing of the sexes. After the egg-laying, the parents, their work being done, may as well die, except in those cases where their exertions are needed to get food for the young. The life of the perfect insect thus tends to be shortened, and even in cases where feeding goes on, the duration of the imaginal state is very brief as compared with the life of the larva. A grub feeds industriously underground for years that a Chafer may live for a few weeks in the upper air. And in the most extreme cases—the May-flies and the Silkworm-moth for example—the jaws are so greatly reduced that feeding by the imago is impossible, and the division of labour between the stages is perfected; feeding is entirely confined to the larva, and the perfect insects have but to pair speedily, lay their eggs, and die.

Larval Reproduction.—But though the reproductive function is eminently characteristic of the perfect state, the pupa of a Midge has been observed to lay eggs, and it occasionally happens that the ovaries become mature during larval life, so that eggs are produced which, without fertilisation, develop within the body of the grub (80), young larvæ being born in an active condition of a larval mother. This very remarkable form of virgin reproduction (known as *pædogenesis*) has been observed in certain Gall-midges (*Cecidomyia*). A yet more astonishing form of premature generation has lately been noticed in a minute insect (Chalcid) parasitic in small caterpillars. The egg of the chalcid (laid in the egg of the moth) gives rise after segmentation not to a single embryo, but, by a process of division, to fifty or a hundred embryos, which develop as their host, the caterpillar, develops. The reproductive function, normally confined to the adult, but thrown back in the Gall-midges occasionally to the developed larva, is in the case of this tiny Chalcid performed by the young embryo (81).

Our short survey of the life-history of insects has shown us the endless variety that can be traced in the methods of their growth from the egg to the perfect form. In the course of the descriptions, attention has occasionally been drawn to what seem plain indications of the steps by which some of these various methods of growth have been brought about. In the simpler and more primitive insects, the young closely resemble the adults; while among insects which pass through a metamorphosis, those with a passive pupal stage are more highly developed than those which move and feed throughout their lives. We may gather from these facts that metamorphosis

has superseded the more simple, direct development, and that the passive pupa has been modified from the active nymph. But we can better attempt to solve the problems presented by the life-history of insects after a brief survey of their various orders and the affinities which these bear to one another.

Chapter III

THE CLASSIFICATION OF INSECTS

What is it? A learned man
Could give it a clumsy name.
Let him name it who can,
Its beauty would be the same.—TENNYSON.

I believe that community of descent is the bond which is partially revealed to us by our classifications.—DARWIN.

Objects of Systematic Zoology. — The studies summarised in the two preceding chapters are due to the labours of men who have devoted their attention to learning the detailed structure of a comparatively small number of typical insects, or to tracing carefully the life-history of a few kinds. Besides students of animals from these points of view—morphologists and biologists as they are called—there are many naturalists who spend their time in a necessarily more superficial study of a larger number of animals, with the object of discovering how many different kinds there are, giving distinctive names to these different kinds, and arranging them in groups which shall express the varying degrees of their likeness or dissimilarity. These workers are the systematic zoologists, and the object of their work is to classify the different kinds of animals in such a way as shall express their relationships. For, as stated in the opening pages of this book, all naturalists work in the belief that animals are really related to each other, representing branches more or less divergent from a

common stock. We have seen already much to confirm this belief so far as concerns insects: that each individual insect passes through a process of growth from very simple beginnings, that the same structure or organ can be variously modified in different insects to perform different functions. The study of insect classification will show us that a gradual increase in the amount of difference between insects can be traced. The subject is vast; it has been calculated that there are more different kinds of insects than of all other animals put together. A quarter of a million have already been described, and it is thought that two millions more yet remain to be discovered! It seems desirable therefore to illustrate the question by means of a few concrete examples.

Variety.—On sunny hillsides in the south of England, a little Butterfly, wings dark brown above with a border of orange spots, can be commonly seen flitting about during the month of June and again during August. It is known to naturalists as *Polyommatus astrarche* (fig. 82). A more careful examination shows in the centre of each forewing a black spot. As the insect rests awhile on some plant and holds its wings raised together over its back, we have an opportunity of observing their under side (fig. 82 *b*). The ground colour is much paler than on the upper surface—a light greyish fawn. Around the margins of all the wings, inside a series of white lunules and black specks, are rows of orange spots, as on the upper side. Internal to these beneath each forewing comes a row of five black spots surrounded by white rings; within these again at the centre of the wing a single black, white-ringed spot. The under side of the hindwing has a number of similar "eye-spots" scattered over its surface, and a triangular whitish patch towards the centre of the space just within the

orange spots. Now and then we may find a specimen showing a reduction in the size of the orange spots, or an edging of white around the central black spot on the upper side of the forewing. Or a reduction in the black of the eye-spots beneath the wings may be noticed, so that instead of describing them as "black with white rings," it would be more accurate to say "white with black centres."

Travelling northward, we notice that this butterfly is much scarcer in the English midlands than in the south. In many places in the northern counties, however, it again becomes common, but we find that most of the specimens here show characters which, in the southern counties, are exhibited only by a few. Above, the orange spots are generally reduced in size or (in the males) almost absent, and the central black spot of the forewings usually has a white ring. The black centres of the eye-spots beneath the wings are small, and sometimes wanting altogether.

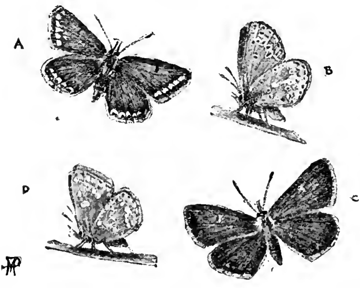


FIG. 82.—"Brown Argus" Butterfly (*Polyommatus astrarche*). *a*. Southern English (typical) female flying, showing upper side of wings; *b*. at rest showing under surface; *c*. male of the Scotch and Irish variety *artaxerxes*, upper side; *d*. under side. Natural size.

Crossing the border into Scotland, specimens of the insect, as it occurs in southern England, may still be met with in the south-western counties. But north-

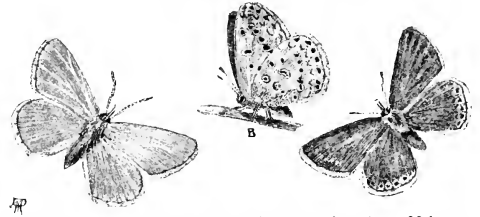
wards—to the Clyde in the west and to Aberdeen in the east—the southern English form is altogether absent, and all the specimens of the butterfly to be found show in an intensified degree the variation characteristic of northern England. The central spot above the forewings is pure white without a trace of black, while the marginal orange spots have almost vanished in the males and are much reduced in the females. The spots beneath the wings are all pure white; only occasionally do some of them show a central black speck (fig. 82 *c*, *d*).

These typical Scotch insects differ so markedly from those found in the south of England that they were formerly believed to belong to a distinct kind. This opinion received confirmation in the fact that while the southern form has two life-cycles in the year (the June butterflies laying eggs which develop into a fresh generation of butterflies in August, the offspring of these surviving the winter as caterpillars); the northern form has but a single brood (the butterflies appearing in June and July, and the caterpillars hatched from their eggs not pupating until the following spring). But the study of the insect in the north of England (especially in Durham) has shown, as we have seen, that both the Scotch and southern forms occur together, and that every intermediate link between them can be found. Moreover, all these diverse forms can be reared from the same batch of eggs. No doubt remains therefore that the Scotch and southern insects are not distinct kinds, but *varieties* of one kind. And instead of writing the name of the Scotch insect as formerly, *Polyommatus artaxerxes*, we write *Polyommatus astrarche* var. *artaxerxes*, the term *variety* being applied where one form differs from another to a recognisable extent, while, nevertheless, intermediate forms are known to bridge over the gap

between the two, and both can be derived from the same parents (141).

Species.—Where, on the other hand, two forms differ from each other in some definite characters, and no intermediate links are known connecting them, they are said to be of distinct kinds or *species*. On the same sunny English hillsides where *Polyommatus astrarche* is found, another commoner, larger and more lively butterfly (fig. 83) may be observed. Its eyes are covered with hairs, while those of *astrarche* are naked. The under side of its forewing differs from that of *astrarche's* in having two additional

A



C

B

FIG. 83.—"Common Blue" Butterfly (*Polyommatus icarus*). *a*. Male, upper surface; *b*. under surface; *c*. female, upper surface. Natural size.

eye-spots near the root. In the female there is, as in *astrarche*, a marginal row of orange spots on the upper surface, which is brown, though dusted over with bright blue scales. But the male of this second kind shows no trace of orange spots on the upper surface, which is of an uniform, beautiful lilac-blue. This insect, then, though resembling *astrarche* in some particulars, differs in a startling way in others. No specimen of *astrarche* has ever been observed with hairy eyes, with blue scales above, or with eye-spots beneath the basal half of the forewing. Moreover,

while the caterpillar of *astrarche* feeds on rock-rose and stork's-bill, that of the blue insect feeds mostly on rest-harrow. No hesitation is felt therefore in referring the latter to a distinct species, and it is known to naturalists as *Polyommatus icarus*. The second of the two names by which every animal is called is the *specific* name; *astrarche* and *icarus* distinguish respectively the two species which we have considered.

"Variety" and "Species."—We have seen that the Scotch form (*artaxerxes*) of *P. astrarche* was formerly believed to be a distinct kind of butterfly from the southern English type, and was only admitted to be a variety of the latter when intermediate links connecting the two were found in northern England. Now it is quite conceivable that the area where the ranges of the typical *astrarche* and the variety *artaxerxes* overlap might at some future time be submerged beneath the sea, and so all the connecting links might become exterminated. Or the same result might be brought about without any such serious geographical change, since the dying out of several species over wide areas has been noticed in recent years. The form *artaxerxes* inhabits the western part of Ireland, in which country the typical *astrarche* is not known to occur at all. The Irish *artaxerxes*, then, is isolated from the English *astrarche* by a sea-channel, and intermediate forms are unknown. And if, as may happen in the future, the Scottish *artaxerxes* should become similarly isolated and the connecting links should die out, no hesitation would be felt in considering the two insects as distinct species. It is impossible to draw any hard and fast line between "species" and "variety"; the use of these terms must depend on

the knowledge and opinion of the naturalist. And that "variety" and "species" express ideas which grade into each other is shown by the introduction of other terms for less or greater degrees of difference. Irregular variation in individuals, such as the appearance of a white border to the central black spot of the forewings in southern *P. astrarche*, is styled "aberration." The more definite characters shown by the northern intermediate form are considered worth ranking as a variety and distinguishing by a name, *P. astrarche* var. *salmacis*. And *artaxerxes* with its comparative constancy over a wide and well-marked area, would be called by some naturalists a "geographical race," by others a "sub-species." Even if the isolation and the extinction of connecting links, which we have imagined, were to happen, some naturalists, finding *artaxerxes*, though distinct in coloration, inseparable by structure from *astrarche*, would prefer to consider it a "sub-species" rather than a "distinct species."

In the majority of cases, however, there will be found general agreement among naturalists in the practical use of the term "species." No one, for instance, is likely to deny that *P. icarus* is "specifically" distinct from *P. astrarche*. But it may be taken for granted that with increased knowledge comes increased difficulty in distinguishing species from each other. The naturalist who knows only British insects easily discriminates between *astrarche* and *icarus*, though the former insect is nearer to the latter than to any other British butterfly. But a study of foreign insects shows us that there are species which help to bridge the gap between them. In order to recall the main differences, we may state them in tabular form.

Icarus.	*Astrarche.*
Wings above lilac blue in male, brown with blue dusting in female.	Wings above brown in both sexes.
No central spot on forewings in male.	A central dark spot present on forewings in both sexes.
No orange marginal spots visible on upper side of wings in male.	Marginal orange spots generally present.
Under side of forewing with two basal spots.	Under side of forewing without basal spots.
Eyes hairy.	Eyes naked.

Now, looking abroad, we find in south-eastern Europe a butterfly, *P. anteros*, whose male has eyes destitute of hairs, while the wings are mostly of a greyish blue colour, though with a distinct black central spot on each forewing, and traces of the orange marginal spots visible above; the area of the wings for some distance within the margins is dark brown. The female has eyes covered with very short hairs; the upper surface of her wings is dark brown, with marginal orange spots and a central black spot on each forewing, as in *P. astrarche*, from which she is distinguished by possessing beneath each forewing a single basal spot. In mountain pastures in the Alps and Pyrenees another species, *P. eros*, occurs. The upper surface of the male's wings resembles in colour *P. anteros*, but there is no central spot on the forewings, nor any trace of orange marginal spots. The female's wings are brown above, but dusted more or less with blue scales, like those of *P. icarus*. And the forewing in either sex, also as in *P. icarus*, has two basal spots beneath, while the eyes are hairy. Reviewing these species we see that those characters wherein *P. anteros* differs from *P. astrarche* lead on to *P. eros*, which itself occupies a middle place between *P. anteros* and *P. icarus*. Examining the variation presented by *P. icarus*, it is found that the two

characteristic basal spots beneath the forewings are sometimes absent, as in *P. astrarche*, while the black centres of the spots of the under side may disappear, leaving these spots pure white as in the form *artaxerxes*. On the other hand the female of *P. icarus* often exhibits variation away from *P. astrarche*, and tends to resemble her own mate, the normal brown colour of the upper surface of the wings giving way to a suffusion of the lilac blue.

The Causes of Variation.—We see, then, that the characters by which two species are distinguished can be traced, at least in their beginnings, to variations arising within the limits of one and the same species. The natural conclusion to be drawn from this is that species are developed out of varieties. Two problems confront us in connection with this question. Firstly, what causes tend to bring about variation? Secondly, by what means are the varietal differences fixed and stereotyped so as to give rise to new species?

It is a matter of common knowledge that any animal resembles to a great extent the parents whence it has sprung. This tendency of animals to transmit their likeness to their descendants is familiar to all nowadays under the name of heredity. Heredity keeps variation within certain limits; for instance, though the upper wing-surface of a female *P. icarus* may be largely blue instead of brown, it is never known to be suffused with yellow or red. On the other hand there is, as we have seen, a tendency, often very considerable, on the part of the offspring of the same parents to differ from one another. Is this tendency to vary transmitted from parents and ancestors like the tendency to keep to a certain extent constant to type? Or is variation due to causes from outside, acting on the animal in the course of its growth? There seems no doubt that, among insects at least,

variation is due both to inherited and to outside causes. For from a batch of eggs laid by the same mother and subject to the same conditions, young varying in many respects can be reared; while it has been proved that by subjecting developing insects to certain definite surroundings, definite variation in certain directions can be induced.

As to the cause of hereditary tendencies to vary, we can only speculate. The suggestion has been made that all variations due to inherited influences—*congenital* variations, as they are termed—are the result of sexual reproduction (57). A moment's thought brings home to one the innumerable multitude of ancestors to which each living creature must owe his being; and the qualities of these ancestors are believed to be passed on in varying proportions to different individual descendants. A question of fact, of the highest interest, which still awaits solution, is whether congenital variation runs in definite directions or whether animals vary in all directions indefinitely. In all probability it will be found that while some characters vary along well-defined lines, others in their variation obey "the law of chance." The amount of variation that may occur is another question of importance. In some insects a continuous series of varieties showing only slight, almost imperceptible differences from each other can be traced. In others, individuals showing considerable modification seem to arise suddenly from normal parents; such variation is said to be "discontinuous." For example, an insect whose foot has usually five segments may give rise to variety with a four-segmented foot. The measurement of nearly 600 male earwigs has shown the length of the tail-forceps (fig. 84) in those insects to vary from 2·5 mm. to 9 mm.; but the majority of specimens did not, as might have been expected, approach

the mean of these two lengths, but were separated into two groups near the extremes with forceps about 3·5 mm. or 7 mm. long (82).

Butterflies have been chosen to introduce the question of variation and species-making, because they, and their relations the Moths, have been made the subject of experimental studies on the influence of outside conditions in modifying the individual. The surroundings of the larva and the pupa control to some extent the appearance of the imago. It has been proved, for instance, that if some butterfly-pupæ be subjected to a low temperature, the perfect insects will be unusually dark in the colour of their wing-patterns. Several European species, which have two-life cycles in the year, show a dark or deeply-marked spring brood (derived from wintering pupæ), and a pale or feebly marked summer brood. It is found that artificial cold is often effective in producing the spring form from summer pupæ, while more rarely the summer form can be reared from winter pupæ kept in a hothouse (83, 84, 85). It is also known that feebly and strongly marked forms of tropical butterflies—formerly regarded as distinct species—are respectively the dry and wet season forms of a single species (86). It appears therefore that cold and moist conditions during the pupal stage have often a direct effect in darkening the colours of the imago. Night-flying moths (Noctuidae) inhabiting the British Islands are as a rule darker in their wing-patterns than individuals of the same

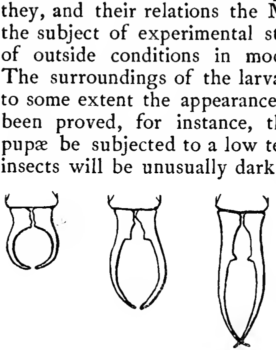


FIG. 84.—Tail-forceps of three male Earwigs (*Forficula auricularia*) showing variation in length and form. Magnified 3 times.

species from the European continent; and within the British Isles, this tendency to dark variation is most marked in moths from Ireland and the hilly districts of northern England and Scotland. In correspondence with these facts we know that the British Isles have a moister climate and a lower summer temperature than Continental Europe, while these conditions are most marked in those highland and western regions where the darkest moths are found (143).

Many other direct effects of surroundings on the variation of insects doubtless await discovery, but the greatest care has to be exercised in making generalisations on the subject. We have a common butterfly in these countries, *Chrysophanus phlœas*, whose wings are of a metallic copper-colour with black spots. In southern Europe a summer-brood of this insect occurs in which the black has largely overspread the copper, and this dark form has been artificially produced by subjecting British pupæ to a high temperature. We must admit, therefore, that the darkening of wing-patterns cannot always be due to the action of cold.

Another exception is furnished by the insect used to introduce the subject of varieties and species; it will be remembered that the black centres of the wing eye-spots of *Polyommatus astrarche* disappear in the Scottish race *artaxerxes*. In this case however it is possible to suggest an explanation. It is commonly taken for granted, since the type-form *astrarche* occurs throughout Europe, extending into northern England, while *artaxerxes* is confined to Scotland and western Ireland, that the latter is an offshoot of the former. But it is far more likely that an animal confined to the western and north-western outposts of Europe is not a new offshoot but a very old type which has become extinct elsewhere. And this view of the case is confirmed when we consider wherein *artaxerxes*

differs from *astrarche:* in the simpler pattern of its lower wing-surface—plain white spots instead of black-centred eye-spots. It is probable, therefore, that *astrarche* is in reality the newer form, and that the Scottish *artaxerxes* does not represent a special development due to climatic conditions, but a survival of an old stage in evolution passed by elsewhere—comparable to the Gaelic speech of the people who share its special homes. It will be remembered also that this same variation—the disappearance of the black centres of the eye-spots—sometimes occurs in *P. icarus*, the other (blue) butterfly mentioned in connection with *P. astrarche*. If the explanation just given be correct, this would be an instance of the occasional reappearance of an ancestral character. Such variations, which recall a past stage in the history of the race, are not uncommon in various animals. They are defined as *atavic* variations.

The Origin of Species.—We have seen that it is impossible strictly to distinguish a "species" from a "variety." There is the strongest presumption that the marked and definite distinctions to which the former term is applied have their origin in varietal differences. The problem of the evolution of distinct species from varieties has now to be faced. The difficulty of this problem was felt to be so great that until forty years ago belief in the fixity of species prevailed generally among naturalists, who thought variation must be kept within such strict limits by the action of heredity that species must ever be and must always have been distinct. A necessary consequence of this belief would be that all kinds of animals originated independently of one another by a process which one cannot even try to explain. This view was abandoned by naturalists, and belief in evolution was adopted mainly through the influence of Darwin,

who suggested that species became differentiated from each other by the process to which he gave the name of Natural Selection (87). An outline of the Darwinian theory may therefore introduce our discussion as to the origin of species among insects.

Natural Selection.—The first great fact on which the theory rests is that variation on which we have just dwelt; the second is the "struggle for existence," which now requires a brief notice. In all animals the number of young produced is greater, in many far greater, than the number which survive. A single female insect lays scores or hundreds of eggs, but the number of individuals belonging to her species does not increase twentyfold or a hundredfold; it remains approximately the same from year to year. Some of the young hatched from these eggs fail to find enough food, others may be drowned or may fall victims to accidents, others may be killed and devoured by creatures of prey. Of the many eggs laid by a moth, for example, only a few give rise to caterpillars which will pass safely through all the changes and chances of their lives, so as to become moths, capable, in their turn, of leaving offspring.

What, then, decides the question which of these young are to die and which to survive? Those will survive which have inherited or acquired the most favourable variations, whether of structure, instinct, or habit, while the less favourably endowed will be exterminated. Thus the struggle for existence leads to a "natural selection" for survival of those animals most perfectly adapted to their surroundings and to their manner of life. And it is believed that different species have become slowly marked off from one another, as, diverging more and more from a common stock, each has attained more and more perfect corre-

spondence with the ever-changing conditions and needs of its life.

The theory of natural selection, by furnishing a reasonable explanation of how the evolution of species might be brought about, has led naturalists to abandon belief in the independent origin of different kinds of animals, and to embrace the view that all living creatures are really related to each other. The origin of species is shown to be a problem capable of solution, to some degree at least, by patient observation and reasoning; and man, no longer content with merely giving names to the living creatures around him, begins to ask how they come to be as he finds them. But though the Darwinian theory has led to the universal acceptance of the evolution doctrine by scientific men, the greatest divergence of opinion still prevails as to the value of that theory in explaining the differentiation of species. While some write of the "all-sufficiency of natural selection" (57), others deny that specific differences are in any way due to its influence (89, 93).

Utility of Specific Characters.—The reality and severity of the struggle for existence cannot be denied, nor is it possible to doubt that a rigorous selection among both individuals and species results from it. But if specific characters have become fixed by the action of this selection, these characters must be of use to the animals possessing them. The strongest reason for doubting that natural selection is the "all-sufficient" cause of the origin of species, is that the characters which distinguish species from each other seem often of no use to their possessors.

For example, there are two nearly-related species of small Beetles often to be found abundantly in stores of flour and meal, on which both the beetles and their grubs feed. They are about a sixth of an inch long,

flat with convex upper surface, and shining reddish-brown. The feelers are composed of eleven segments. In one of the species—*Tribolium confusum*—these segments gradually increase in breadth from base to tip of the feeler, and the head is widened in front of the eyes (fig. 85 *a*, *e*). In the other—*T. ferrugineum*—the three terminal segments of the feeler are markedly wider than the rest, forming a club, while the head is not widened in front of the eyes (fig. 85 *f*). Moreover, the wing-cases are less deeply

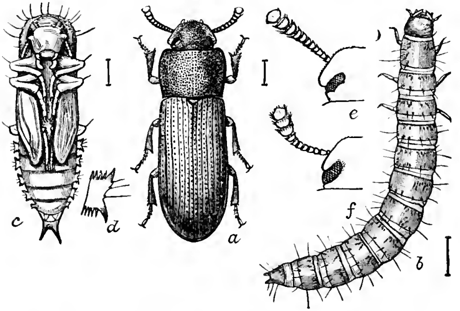


FIG. 85.—Flour-Beetles. *a. Tribolium confusum; b.* larva; *c.* pupa; *d.* process of abdominal segment; *e.* head of beetle; *f.* head of *T. ferrugineum.* Magnified. From Chittenden, Bull. 4 (n.s.) Div. Ent. U.S. Dept. Agr.

punctured in *T. confusum* than in *T. ferrugineum*.

Now it must be admitted that such differences as these seem to have no relation to the insects' success in the struggle for existence. Moreover, as the habits and surroundings of these two species are precisely alike, it is hard to say why they should differ at all if natural selection be the only cause of specific differences. Yet we know far too little about the relations that may exist between the smaller details of structure

and the manner of life of insects to state dogmatically that such characters as these can be of no value to the species. For instance the difference in the feelers may be no mere useless difference of shape. These appendages are the seat of the senses of touch and smell, and the modification of the terminal segments into a club where sensory hairs are specially numerous —as in *T. ferrugineum*—is a distinct advance on the simpler feelers of *T. confusum*. And it is to be noticed that, though both species occur together in our country, the former is decidedly more common than the latter, as though it were the dominant species, the winner in the struggle, supplanting its less perfect rival. Both these beetles have been imported into North America; there, at least in the northern States, *T. confusum* is the more abundant of the two, *T. ferrugineum* not having apparently been introduced in sufficient numbers to press heavily on its rival in that country.

Correlation.—But if a possible use for one of the specific differences between these two species can be suggested, what is to be said of the other characters which distinguish them—thé distinction in the breadth of the head and the punctures on the wing-cases? It is conceivable that characters like these, even if useless in themselves, may be *correlated* with useful characters or qualities, may be, that is, the necessary accompaniments thereof. Hence indirectly if not directly they may be due to the action of natural selection.

Alternatives to Natural Selection.—But so long as it is impossible decidedly to ascribe all specific characters to natural selection, so long will naturalists speculate on other factors of evolution. Many believe that the direct action of the surroundings is effective not only in inducing variation but in fixing

specifically the characters thus acquired (89, 90). If this opinion be correct, it is necessary to suppose that characters acquired in the lifetime of an individual, or recurring habitually through a sufficient number of generations, can become so fixed in the race as finally to be transmissible by heredity. The extreme upholders of natural selection deny that such transmission of acquired characters ever takes place, and few, if any, undeniable proofs that it does have yet been adduced. The darkening of the wing-patterns of moths through the influence of cold during the pupal stage has already been referred to, but the offspring of these dark-hued insects require a repetition of the same conditions in order that they may resemble their parents. It may be objected with some reason that observation on a single generation only is not sufficient to decide the point. That acquired characters may in the course of several generations become hereditary is what might have been expected; if this does occur, it must doubtless contribute largely to the progress and evolution of animal races. But until definite proof of its common occurrence is forthcoming, it is wise to suspend judgment on the subject.

Closely connected with the action of the surroundings, and also depending for its efficiency in species-making on the supposed inheritance of acquired characters, is the influence of use and disuse (89). This was suggested as a cause of evolution years before the work of Darwin by the French naturalist, Lamarck. Just as in the individual, those organs which are most exercised become most highly developed, while those whose functions are neglected become degenerate, so in the race it is believed that various parts have become modified in response to the activity or passivity of the animal. On this view

the broad fore-limbs of earth-burrowing insects like the Mole-cricket are the direct result of a digging-habit persevered in through many generations, while the wingless condition of many female and parasitic insects is simply due to their ancestors having given up flying. It is hardly necessary to point out how differently the natural selection theory accounts for such facts as these. According to its advocates no amount of the most vigorous digging on the part of a primitive cricket would avail to provide his descendants with broad fore-legs; these organs are believed to have been slowly specialised through a long series of generations of crickets, who were adopting the burrowing habit, through the selection in each generation of those individuals best adapted for burrowing, that is, those who possessed the broadest and strongest fore-legs, the broadening not being an acquired but a congenital character. And there is no doubt whatever that congenital characters are transmissible. In the same way it would be believed that the loss of wings in the insects mentioned above being, for some reason, actually beneficial to the species, individuals with the smallest wings were selected through numerous generations until those organs were almost or entirely lost.

The efficacy of natural selection in fixing specific differences depends largely on the indefiniteness of variation. If animals vary, so to speak, in all directions, natural selection must play a most important part in eliminating the unfavourable and preserving the favourable characters. But if variation takes place along definite and determined lines, the action of natural selection must be confined to exterminating the weakly and feeble, and preserving the healthy and strong; it can do nothing to fix specific characters, since it can have no "choice of

material" whereon to work. Hence the origin of species has been ascribed by some to an innate direct tendency in animals to vary in certain definite directions. It has been pointed out how, among butterflies, regular modification in the wing-patterns can be traced through a succession of nearly-related species. And as these differences in pattern seem to be of no use to the insects in the struggle for life, they are supposed to be due to an inherent tendency to vary along definite lines, under stimulation from outside influences—such as changes in climate (90). The nature of variation still calls for a vast amount of study, but it seems impossible to claim either that variation is always indefinite or that it is always necessarily determined along certain fixed lines.

In the preceding pages an attempt has been made briefly to put forward the various current explanations of the origin of species. While the author of this little book believes that the Darwinian theory is largely supported by facts, and that the alternatives which have been proposed to supersede it rest to a great extent on unproved theories, he cannot subscribe to the "all-sufficiency" of natural selection. The insect-world presents us with such varied and complicated features that it is hard to believe that the origin of its myriad kinds can be explained by any one agency.

Prevention of Intercrossing.—One other point demands attention before we pass from the question of the origin of species. An objection which has been urged against the development of species out of varieties is that the incipient species would be "swamped" by intercrossing with the parent form. Varieties of the same species usually breed freely among themselves, but hybrids between two distinct species are rare in nature, and when they do occur

are, as a rule, infertile. It has indeed been proposed to make the infertility of hybrids the test of "specific distinctness." But experiments have shown, in the case of the European "Emperor" moths for instance, that a male hybrid can be crossed with a female of one of its parent-species so as to produce offspring (**85**). Such occurrences must, however, be very rare in nature; and it is evident that if intercrossing between different species were at all general, specific distinctions would soon vanish.

There are various ways in which intercrossing can be prevented (**91**). A variety in process of development into a new species may be geographically isolated from its parent stock, having migrated into a new locality, where changed conditions are inducing modification in its form or appearance. There may be a preference on the part of individuals to pair with members of their own variety or race; this factor, though of undoubted value among back-boned animals, is probably of little effect among insects. Intercrossing may be rendered impossible by a difference in the time of year at which the two separating forms become mature. A very interesting case of this form of isolation is furnished by two British moths—*Tephrosia crepuscularia* and *T. bisortata*, so closely related that it is almost impossible to distinguish them by structural characters, yet with distinct life-cycles, the former appearing in the perfect state once a year during May and June, the latter in March and April and again in July. In many insects intercrossing is rendered impossible by variation in the genital armature; the male claspers become so modified that they will only fit the corresponding parts of a female of their own race. The well-known North American "seventeen-year Cicad" has a larger and a smaller race or sub-species, which usually differ markedly in

the form of their male claspers (*fig.* 86 *c*, *d*, *e*, *f*); these differences however are not perfectly constant, and it is evident that the two forms are still in process of separation from each other. Similar differences have been noticed in the races of various butterfly-species, while two nearly related wasps, *Vespa vulgaris* and *V. germanica*, have been observed trying to effect sexual union, but vainly, on account of the difference in their genital armature. There can be no doubt that intercrossing among insects is largely prevented by this means, to which the name of "mechanical selection" has been applied (92).

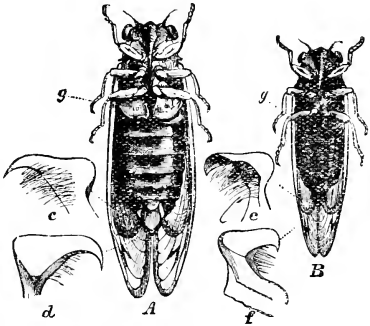


FIG. 86.—*A*. *Cicada septemdecim*, male; *c*. *d*. its genital claspers; *B*. *C*. *septemdecim*, var *Cassinii*, male; *e*. *f*. its genital claspers. (*A*. *B*. natural size, *c*. *d*. *e*. *f*. enlarged). From Marlatt (after Riley and Hagen), Bull. 14 (n.s.) Div. Ent. U.S. Dept. Agr.

Genus.—It is now necessary to deal with the more comprehensive divisions into which species are grouped. Returning to the two butterflies mentioned in the early pages of this chapter, as examples of distinct species, we remember that the brown one is known as *Polyommatus astrarche*, the blue as *Polyommatus icarus*, the names *astrarche* and *icarus* being specific, serving, that is, to distinguish the species to which they are applied. But it will be noticed that the first of the two names applied to each of these insects,

Polyommatus, is the same for both species. It is the *generic* name, and indicates that the two butterflies are so closely related to each other that they are classed by naturalists in the same *Genus*, a genus being an assemblage of species which possess so many characters in common as to suggest that they have not diverged very widely from their common stock. The genus Polyommatus takes its name from the numerous eye-spots on the under side of the wings of the butterflies included in it. These, together with the marginal orange spots beneath the hindwings, are the most characteristic markings of the group. In the vast majority of the species, as in *P. icarus*, the upper surface of the wings is some shade of blue in the male, brown with blue dusting in the female.

There is another blue butterfly found in our islands which frequents woods and thickets rather than the open hillside where one finds the species of Polyommatus so abundantly. The upper surface of the wings in both sexes is lilac blue, the female being distinguished by a black border along the termen of the forewing. Beneath, the wings are very pale blue, each with a central half-moon-shaped black spot, between which and the termen comes a row of small circular black spots; the hindwing has in addition a few black basal spots. None of the spots are "eyed," nor are there any orange spots at all. This insect, whose specific name is *argiolus*, is the only British butterfly which exhibits such markings beneath the wings, but many similar species are known in other parts of the world. Its typical markings differ so from those of Polyommatus that most students of butterflies regard it as belonging to a separate genus, *Cyaniris*, and call it therefore *Cyaniris argiolus*.

But just as the terms "variety" and "species" are incapable of strict definition and depend largely on

the personal opinion of the naturalist who uses them, so "genus" is a conception which differs in extent and value in the minds of different students. In markings Cyaniris is readily distinguishable from Polyommatus, but in structure it is hard to find much difference between the two, except that the wings of the former are somewhat the more rounded in outline. On account of this similarity in structure some naturalists would refuse generic rank to Cyaniris, and either call our last-described insect *Polyommatus argiolus*, or, degrading Cyaniris to the level of a "sub-genus," would write the name *Polyommatus* (*Cyaniris*) *argiolus*.

As an insect universally admitted to belong to a genus distinct from Polyommatus, we may take the copper-coloured butterfly *Chrysophanus phlœas*,[1] mentioned before in this chapter.

If the scales be removed from the wings of one of the blue butterflies, so as to render the neuration clearly visible, it is found that the first branch of the median nervure in the forewing (fig. 87 iv_1) is separate from the radial system (fig. 87 iii), while the space (discoidal cell) near the base of the wing between the radial (iii) and the cubital (v) nervures

[1] In precise zoological nomenclature, the name of the author who first described a species is written after the specific name (usually in an abbreviated form), as *Chrysophanus phlœas* (Linn.). The parenthesis indicates that Linné, who named the species, referred it to a comprehensive genus (*Papilio*), whence Chrysophanus was afterwards separated. Where a species has not been removed from the genus adopted by its original describer, the bracket is not used, as *Forficula auricularia*, Linn. A second or later name given to a species is known as a *synonym*, and the tracing of synonymy is often a laborious task. The specific name *alexis*, for example, has been applied both to *Polyommatus astrarche* (by Von Rottemburg) and to *P. icarus* (by Denis and Schiffermüller). Consequently the name *alexis* without an authority conveys no certain idea which of the two species is meant. For the latest rules of zoological nomenclature, see (94).

is closed at the end by too small cross nervules (the discocellulars), which make an obtuse angle with each other. But in the forewing of Chrysophanus the first median branch is fused with the radial for a great part of its length, while the upper discocellular nervule is absent. These differences, though they may seem exceedingly slight, are found to hold constantly throughout a vast number of species. Moreover, such characters, not being affected by the insects' manner of life, are specially valuable in indicating relationships, since they have presumably been transmitted through many generations with very little change.

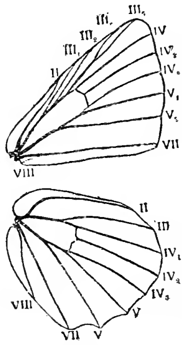


FIG. 87.—Neuration of wings of *Lycæna*. II. sub-costal; III. radial; IV. median; V. cubital; VI.-VIII. anal nervures. Twice natural size. From Grote, Natural Science, vol. 12.

Family.—In the main features of their structure, however, Chrysophanus and Polyommatus are closely alike. With the exception of the distinguishing points mentioned above, they agree in the neuration of the wings, the even spacing of the various nervures as well as the termination of the last radial branch (fig. 87, iii_5) at the extreme tip of the forewing being specially characteristic. If we examine their legs, we find that all three pairs are developed in both sexes, though the front pair are feebler in the male than in the female. Turning to the immature stages, the caterpillar is, in both genera, short, stout and hairy, in shape somewhat resembling a wood-louse, while the pupa is rotund in form and covered with hairs or

bristles. These genera, therefore, with many others which agree with them in these main structural features, are classed together in a single *Family*—the Lycænidæ, which derives its name from Lycæna—a genus of blue butterflies which differs slightly both from Polyommatus and Cyaniris.

As an example of a distinct family, we may take a

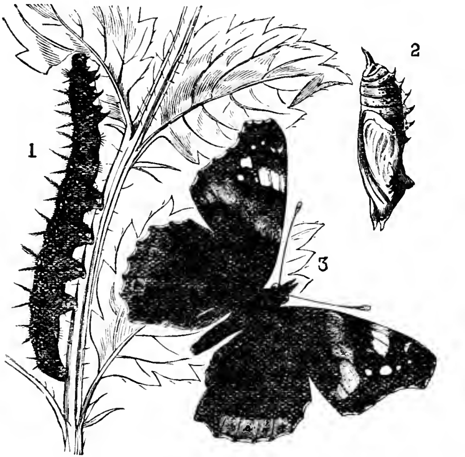


FIG. 88.—"Red Admiral" Butterfly (*Pyrameis atalanta*). 1. Caterpillar; 2. pupa. Natural size.

considerably larger butterfly than those hitherto examined—the handsome black, white and scarlet-winged species known as the "Red Admiral"—*Pyrameis atalanta* (fig. 88). Its whole appearance is strikingly different from that of the "Blues," yet appearance is not always a safe guide in classifying

insects. But very distinct structural characters are soon apparent. Examining the forewing of Pyrameis or of an allied genus (fig. 89) we find that the little anal vein (fig. 87 viii) of the Lycænidæ is quite wanting; there are five radial branches, whereas in the "Blues" there are but four, while the almost complete suppression of the discocellulars leaves the cell "open." Turning to the legs we find that those of the front pair in both sexes have become quite useless for walking, the foot being absent, while the shin, clothed with long hairs, serves as a brush, the insect going on four legs. The caterpillar of Pyrameis is elongate and armed with many strong spines, while the pupa, quite devoid of hairs, is studded with tubercles (fig. 88, 1, 2). Such differences in structure as these warrant separation more marked than that between genera. Pyrameis belongs to a family—the Nymphalidæ—abundantly distinct from the Lycænidæ.

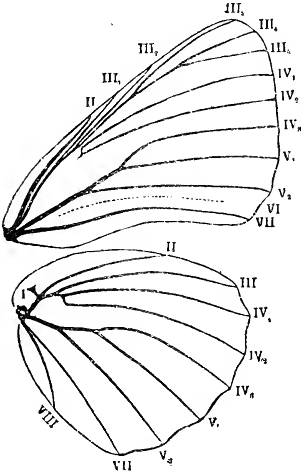


FIG. 89.—Wing-neuration of *Nymphalis*. I. II. sub-costal; III. radial; IV. median; V. cubital; VI.-VIII. anal nervures. Twice natural size. From Grote, Natural Science, vol. 12.

Flying about wood-clearings may be found a

brown and grey speckled butterfly intermediate in size between the "Blues" and Pyrameis. Its name is *Pararge egeria*. Studying its structure we find that its wing-neuration (fig. 90) agrees with that of Pyrameis in the presence of five radial branches, and in the absence of the small anal nervure; but differs in the presence of discocellulars, closing the cell, and in a marked thickening of the main nervures at the base of the wing. Like Pyrameis, it is a "brush-footed" butterfly, walking on four legs only. Its caterpillar is elongate, though hairy not spiny; its pupa rotund and without tubercles. It is usually referred to a family distinct from the Nymphalidæ—the Satyridæ. Yet it agrees with the Nymphalidæ in the striking character of the aborted front legs and does not differ markedly in its type of wing-neuration; evidently it is nearer to the Nymphalidæ than to the Lycænidæ. Some naturalists would express this fact by classing Pararge and its allies as a *sub-family* of Nymphalidæ, calling them Satyrinæ.[1] Others, allowing them family rank, would group them together with the Nymphalidæ and other allied families into a *super-family*, to which they might give the name of Nymphalides.

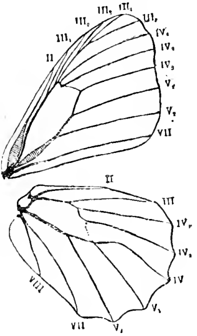


FIG. 90.—Wing-neuration of *Pararge egeria*. II. subcostal; III. radial; IV. median; V. cubital; VI.-VIII. anal nervures. Twice natural size. From Grote, Natural Science, vol. 12.

[1] Throughout the animal kingdom family names end in i*dæ*, sub-family in i*næ*, both being compounded from the name of the typical genus as *Lycæna*, *Lycænidæ*.

Order.—But all these insects, though referred to two or three different families, are Butterflies. All agree in the essential points of structure. The mandibles are reduced to the merest vestiges, while the blades of the first maxillæ are absent and the hoods are greatly lengthened and form a tubular sucking organ, capable of being spirally rolled up beneath the head or stretched out into the corolla of a flower or other desirable feeding-place. The wings are densely clothed with scales, and the neuration (except for the discocellulars when present) is entirely made up of longitudinal nervures radiating from the base towards the margins and angles of the wing; there is no network of nervures as in the wings of the cockroach. The larvæ of these butterflies, though differing in shape and appearance, are all creeping caterpillars with several pairs of prolegs on the hind-body in addition to the three pairs of thoracic legs. Their pupæ are all passive and obtect. Agreeing as they do in these features, the Lycænidæ, Nymphalidæ, and Satyridæ are classed together with the many other families of butterflies and moths, most of which differ far more from these families than they do from one another in the single *Order* of the *Lepidoptera* or scale-winged insects One family of very small moths (Micropterygidæ), on account of the presence of fairly developed mandibles, and of blades to the first maxillæ—characters unknown throughout the rest of the order—is placed by some naturalists in a separate *Sub-order* (*Laciniata*), all the other moths and butterflies forming another sub-order (*Haustellata*). In several of the orders it is convenient thus to segregate the families into sub-orders. And it is of great interest to note that the limits of orders, like those of species, genera and families, are often uncertain. This sub-order Laciniata shows in its

structure a marked approach to the Caddis-flies which form the order Trichoptera usually held to be distinct from the Lepidoptera.

Comparing now the Butterflies which we have just been studying with the Cockroach wherewith we began our enquiries into insect-structure, we notice that it does not possess any one of the features mentioned above as characteristic of the Lepidoptera. It has strongly developed mandibles, and the first maxillæ are primitive jaws not in the least modified as a sucking-organ. The wings differ markedly in shape from those of Butterflies or Moths, are totally devoid of any scaly covering, and have their surface covered by a close network of nervures. The young Cockroach is hatched from the egg in a form closely resembling its parent, except that it has no wings. Differing thus, there can be no hesitation in referring the Cockroach to an order of insects entirely distinct from the Lepidoptera. It belongs to the order of the *Orthoptera* or straight-winged insects.

Commencing an enquiry into the classification of insects with the difference between two varieties of butterfly we have passed upwards through increasing divergences of form to the distinction between some of the Orders into which the whole *Class* of insects is divided. In classifying any individual insect, it is evident that the reverse order to this must be followed; the order must first be determined, then the family, then the genus, and finally the species and variety.

The Search for a Natural Classification.—It will have been evident to the reader of this chapter that insect-classification is a more or less uncertain thing. The limits which mark off species, genera, families, and even orders from each other depend largely on the judgment and opinion of the naturalist.

Butterflies and Moths may be easily enough distinguished from Cockroaches, but some of them show a remarkable likeness to Caddis-flies. This difficulty in classification is just what we should expect, if, as we believe is the case, all insects are really related to each other. We are able to draw hard and fast lines between some groups because in the course of ages they have diverged far from their common stock. But the more nearly related insects are, the more difficult do we find it to make them fit into the divisions that we have made for their reception. Could a naturalist have before him all the insects which live or ever have lived on the earth, his divisions would entirely break down, and his system of Species, Genera, Families and Orders would become lost in a well-nigh indefinable gradation of characters. The object of the classifier is so to arrange the insects which he does know that they may fall into their right positions with regard to these vanished races that must once have formed the connecting links between them. The truly natural classification of insects is that which will place them on their right branches of the great tree of animal life. The labours of the classifier are usually presented in the form of lists or catalogues; and no linear arrangement—genera, families, orders, following one after the other—can exactly express the true relationships between the groups, which must necessarily show affinities in various directions. But in striving after a natural system, making use in his work of all that he can learn of the inner and outer structure and development of the creatures which he classifies, the systematist is doing his part to read the *history* of insects in the widest sense of the term. And he will, if wise, hold with a light grasp to his systematic divisions, recognising that the increased

knowledge which makes the line between two species or two orders appear blurred and uncertain, throws a clearer light on the object of all entomological work, which is to trace the course of evolution in insect life.

Chapter IV

THE ORDERS OF INSECTS

You are to know that there are as many sorts of Flies as there be of Fruits: I will name but some of them . . . and indeed too many either for me to name or for you to remember: and their breeding is so various and wonderful that I might easily amaze myself and tire you in a relation of them.—IZACK WALTON.

IN the closing pages of the preceding chapter examples were given of the characters whereby insects are grouped into distinct Orders. The Moths and Butterflies form, as we have seen, an order (Lepidoptera) to which the Caddis-flies (Trichoptera) are nearly allied. The Cockroach, on the other hand, belongs to an order—the Orthoptera—far removed from the Lepidoptera, the two orders differing markedly in the nature of the jaws, wings and life-histories of the insects included in them. Jaws, wings, and life-histories are the leading characters by which insects have been divided into orders, but the different values assigned to these characters by different naturalists have led to considerable divergence in the orders recognised.

There are several well-marked groups of insects, however, universally admitted to form natural orders. Those, for example, whose jaws are formed for piercing and sucking like the Cicad described in Chapter I (p. 16)—Bugs, Lice, Plant-lice, Scale-insects, Frog-hoppers—are all included in the order of beaked insects (Hemiptera). Their jaws are so peculiar and characteristic that no doubt is felt that they are nearly

allied to one another in spite of considerable differences in the nature of their wings and in the details of their life-histories. The Flies whose hindwings are reduced to stalked knobs form an easily recognised order (Diptera), as do the Beetles (Coleoptera) with their horny forewings and powerful biting jaws. Flies and Beetles agree with the Lepidoptera in passing through a passive pupal stage. This character of the life-history is shared also by the insects of another universally recognised order, the Hymenoptera, which are distinguished by the possession of four clear net-veined wings (the hind-pair being always much smaller than the front pair), and biting mandibles. The leading features of the Orthoptera have already been mentioned. A few families of small wingless insects, Springtails and Bristletails, with jaws withdrawn into the head capsule, or with abdominal limbs present throughout life, make up the orders Collembola and Thysanura.

The vast majority of the families not included in the orders hitherto mentioned agree in the possession of four membranous, net-veined wings and biting jaws. On this account they have often been regarded as forming a single order, the Neuroptera (3). But such divergence is to be found among these insects in their life-histories and in many details of their structure, that by most modern students they are divided into six or seven different orders (96, 97). Objection may be taken to whichever of these two courses be followed. The difference between a Termite and a Dragonfly is less marked and conspicuous than that between a Moth and a Beetle, and therefore it may be urged that the same term should not be used to define such uneven distinctions. But we have seen that all the terms used in insect classification must bear values differing in different

cases. Orders, like species and families, are often hard and sometimes impossible to define; our "little systems" can but imperfectly express our imperfect knowledge of the creatures we study. And when it is extremely doubtful that a number of families are really akin to one another, despite their common possession of certain superficial characters, it is better not to include them in a single order and thereby imply their kinship. Accordingly, in the arrangement here suggested, the old Neuroptera have been distributed among several orders.

Order 1. **Collembola** (Springtails).—Wingless insects with not more than six apparent abdominal segments, of which the first usually bears a ventral tube and the fourth or fifth a spring consisting of a pair of partially fused limbs. Jaws withdrawn into the head. No metamorphosis.

Order 2. **Thysanura** (Bristletails).—Wingless insects with ten abdominal segments, most of which bear short pairs of limbs, the hindmost pair usually forming long cercopods. No metamorphosis.

Order 3. **Dermaptera** (Earwigs).—Insects with biting jaws, the second maxillæ incompletely fused; with small leathery forewings, beneath which the delicate hindwings are folded both longitudinally and transversely; (wings are often absent). A pair of forceps at hinder end of body. Genital ducts without chitinous lining. Kidney-tubes numerous. No metamorphosis.

Order 4. **Orthoptera** (Cockroaches, Leaf-insects, Locusts, and Crickets).—Insects with biting jaws, the second maxillæ incompletely fused. All wings net-veined, the forewings of firmer texture than the hindwings, which are folded fan-wise beneath them. Kidney-tubes numerous. No metamorphosis.

Order 5. **Platyptera** (Biting-lice, Book-lice, Termites, Stone-flies).—Insects with biting jaws and four similar membranous wings (wings are often wanting). Kidney-tubes few except in Stone-flies. Metamorphosis none or slight. (The nymphs of Stone-flies are aquatic with tracheal gills).

Order 6. **Thysanoptera** (Thrips).—Insects with piercing and sucking jaws; mandibles bristle-like, maxillæ with palps. Fore and hindwings similar, narrow and fringed. Kidney-tubes few. Metamorphosis none or slight.

ORDER 7. **Hemiptera** (BUGS, LICE, CICADS, PLANT-LICE, &c.).—Insects with piercing and sucking jaws, the needle-like mandibles and first maxillæ working within a tube formed by the union of the second maxillæ; no palps. Kidney-tubes few. Metamorphosis none (Bugs, Lice), incomplete (Cicads), or almost complete (male Scale-insects).

ORDER 8. **Plectoptera** (MAYFLIES).—Insects with vestigial jaws, delicate net-veined wings, the hind pair being much smaller than the front pair, and long tail cercopods. Genital openings paired, the ducts without chitinous lining. Kidney-tubes many. Incomplete metamorphosis, the larvæ aquatic with tracheal gills; a sub-imaginal stage before the final moult.

ORDER 9. **Odonata** (DRAGONFLIES).—Insects with short bristle-like feelers, powerful biting jaws and four sub-equal net-veined wings of glassy texture. Male genital armature on second abdominal segment. Kidney-tubes many. Incomplete metamorphosis, the larvæ and nymphs aquatic.

ORDER 10. **Neuroptera** (ALDER-FLIES, LACEWING-FLIES, SCORPION-FLIES).—Insects with prominent feelers, biting jaws, and four similar net-veined wings. Kidney-tubes few. Complete metamorphosis, larvæ campodeiform, rarely eruciform.

ORDER 11. **Coleoptera** (BEETLES).—Insects with the prothorax free and large; forewings strongly chitinised, forming sheaths for the membranous hindwings which can be folded beneath them. Mandibles well developed for biting. Kidney-tubes few. Complete metamorphosis; larvæ campodeiform or eruciform.

ORDER 12. **Trichoptera** (CADDIS-FLIES).—Insects with four hairy wings, the forewings usually longer and narrower than the hindwings. Mandibles present in pupa but absent in imago, which has the two pairs of maxillæ partly fused to form an imperfect sucking apparatus. Kidney-tubes few. Complete metamorphosis; the eruciform larvæ are aquatic.

ORDER 13. **Lepidoptera** (MOTHS AND BUTTERFLIES).—Insects with four scaled wings. Mandibles absent or vestigial in imago, very rarely present in pupa. First maxillæ with galeæ much lengthened and grooved, forming when united a perfect sucking tube; palps rarely, laciniæ very rarely present. Kidney-tubes few. Complete metamorphosis; the larvæ are eruciform (caterpillars) with three pairs of thoracic legs and two to five pairs of abdominal prolegs.

ORDER 14. **Diptera** (FLIES AND FLEAS).—Insects with the forewings developed (rarely wanting) and the hindwings reduced to stalked knobs. Mandibles and blades of first maxillæ, if present, adapted for piercing; hoods of second (?) maxillæ for sucking. Kidney-tubes few. Complete metamorphosis; larvæ eruciform.

ORDER 15. **Hymenoptera** (SAWFLIES, GALLFLIES, ICHNEUMON-FLIES, ANTS, WASPS, BEES).—Insects with four similar membranous wings, of which the front pair are the larger. Mandibles present. The first abdominal segment joined to the thorax. Kidney-tubes many. Complete metamorphosis; larvæ eruciform.

Various groupings of these orders into larger divisions ("super-orders" or "sub-classes") have been proposed. All insects with biting jaws—such as Orthoptera, Coleoptera, Hymenoptera—are sometimes united together as Mandibulata, while those with sucking or piercing mouth-organs—such as Hemiptera, Lepidoptera, Diptera—are classed as Haustellata. In other arrangements greater stress is laid on the nature of the life-history, those insects hatched in a state like their parents being styled Ametabola, those with a distinct larval, but no resting pupal stage Hemimetabola, and those with such a pupal stage Holometabola. In the synopsis just given, orders 1-7 are Ametabola, 8 and 9 Hemimetabola, 10-15 Holometabola. Another system of nomenclature indicates the nature of the jaws both in the nymphal or larval and in the perfect stage. Insects which have biting jaws throughout life (*e.g.* Coleoptera) are Menognatha, those with sucking jaws throughout life (Hemiptera) are Menorhyncha, while those with biting jaws as larvæ and sucking jaws as imagos (*e.g.* Lepidoptera) are Metagnatha. It has also been proposed to lay stress on the kidney-tubes, whether they be many (Polynephria) or few (Oligonephria). The first two orders—Collembola and Thysanura—have been separated, as Apterygogenea, from all the rest (Pterygogenea), their wingless condition being regarded as an ancestral character, whereas wingless insects in other orders are evidently degraded forms (96). These various divisions are merely mentioned for the present. They raise questions of high interest

as to the relations between the orders, which will be discussed in the concluding chapter.

The pages immediately following are devoted to a short survey of the leading features of the various orders, and of the principal families into which they have been divided. This survey is, of necessity, very brief and incomplete, those characters being specially dwelt upon which serve to distinguish the various groups from each other. It is hoped that enough guidance is given to enable the student to trace an unknown insect to its correct family, and that the references to special literature will then help him to detailed information. The interesting subject of habit is very briefly mentioned in this summary of the orders and families, being dealt with in relation to insects as a whole in the next chapter—that on "Insects and their Surroundings."

ORDER I.—COLLEMBOLA.

Structure.—The SPRINGTAILS, which are comprised in this order, are wingless insects of small size, usually without air-tubes. The feelers have few segments (4-6) and the jaws pushed back into the head-capsule (fig. 91 *g*). A variable number of simple eyes, from one up to eight may be present on either side of the head; but many springtails are quite blind. In front of the eyes and behind the feelers an oblique groove or rounded depression is often present wherein are situated a number of tubercles forming a "post-antennal" organ of unknown sensory function (fig. 91 *i*). The prothorax is the smallest of the three segments of the fore-body. The legs have no tarsal segments, a large upper and (sometimes) a narrow lower claw being inserted at the end of the shin (fig.

91 *d*, *e*). There are six evident abdominal segments, whereof the fourth is often much longer than the others; the first segment bears a ventral tube possibly formed by the union of a pair of appendages.

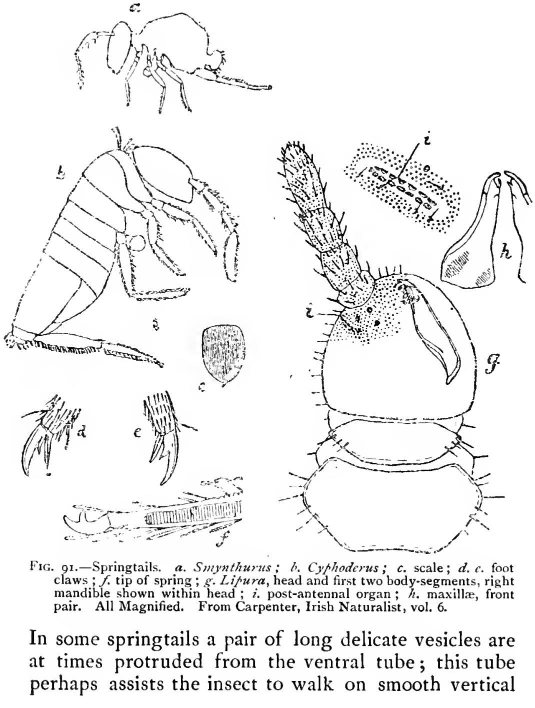


FIG. 91.—Springtails. *a. Smynthurus; b. Cyphoderus; c.* scale; *d. e.* foot claws; *f.* tip of spring; *g. Lipura*, head and first two body-segments, right mandible shown within head; *i.* post-antennal organ; *h.* maxillæ, front pair. All Magnified. From Carpenter, Irish Naturalist, vol. 6.

In some springtails a pair of long delicate vesicles are at times protruded from the ventral tube; this tube perhaps assists the insect to walk on smooth vertical

surfaces, or it may be of use for breathing. On the fifth or the fourth abdominal segment is situated the spring, which consists of a basal unpaired segment—the *manubrium*, whereto the paired *dentes* forming the "fork" are attached; each dens bears at its tip a *mucro* sometimes clawed (fig. 91 *f*) and sometimes clubbed. The spring is usually carried tucked beneath the insect's body with its tip pointing forwards; as the spring is released and straightened out so that its tip points backwards, the creature leaps into the air. A small appendage, the "catch," found beneath the third abdominal segment in some genera, is believed to keep the spring in place by holding the end of the manubrium. The bodies of Springtails are covered with simple and clubbed hairs, and often with flattened scales (fig. 91 *c*) (**3, 98, 99, 100**).

Habits.—Springtails live in concealed situations beneath stones or the bark of trees, in moss or damp earth; several species live on the sea-shore. A number of individuals of a species are usually associated together. They feed on decaying vegetable matter and on the organic particles contained in the mould which they swallow.

Three families of Collembola are recognised; all are probably of world-wide distribution.

Smynthuridæ.—The *Smynthuridæ* are characterised by their unscaled globular bodies, the various segments being partially fused together. The feelers are elbowed, the long fourth segment forming a flagellum; sometimes this segment is ringed or imperfectly jointed. A well-developed spring is present on the fifth abdominal segment. Alone among springtails, the Smynthuridæ possess a tracheal system. A pair of air-holes on the head behind the feelers—a most unusual situation in insects—lead to sets of tubes branching all over the body. *Smynthurus* (fig. 91 *a*) and *Papirius* are the only two genera of the family.

Entomobryidæ.—The *Entomobryidæ* have the head pointing downwards and the body elongate with clear segmentation. Scales are present in some genera, absent in others. The feelers are not elbowed, but in one genus (*Tomocerus*) the third and fourth segments

are greatly elongated and many-jointed, so that they can be spirally coiled. A well-developed spring is borne on the fifth abdominal segment (in a few species only, on the fourth). *Cyphoderus* (fig. 91 *b*), *Tomocerus* and *Isotoma* are typical genera.

Poduridæ.—The *Poduridæ* are distinguished from the Entomobryidæ by the forwardly directed head and the spring when present, being borne on the fourth abdominal segment instead of on the fifth. But in various genera of the family this organ can be traced through all stages of degeneration until it vanishes altogether. The ventral tube is reduced to a small tubercle, and the body is never scaled. Typical genera are *Podura*, *Achorutes*, *Lipura* (fig. 91 *g*, *h*, *i*) and *Anurida*.

ORDER 2.—THYSANURA.

Structure.—The Bristle-tails are wingless insects, of small or moderate size, with long, many-jointed feelers; in some cases with compound eyes. The prothorax is often the largest segment of the body, and the legs are provided with tarsal segments. The hind-body consists of ten evident segments, whereof the tenth bears a prominent pair of appendages—usually many-jointed cercopods (fig. 92). The most characteristic structural feature of the family is the presence of small paired limbs on several of the abdominal segments; these are situated near the hind margins of the sternites. Associated with

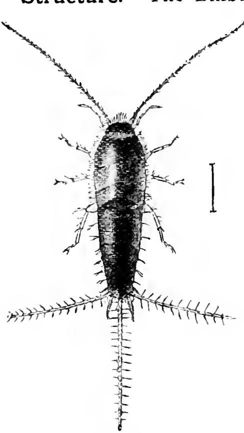


Fig. 92.—Spring-tail (*Lepisma saccharine*, Linn.) Europe. Magnified 4 times. From Marlatt, Bull. 4 (n.s.) Div. Ent. U.S. Dept. Agr.

these limbs are protrusible vesicles, which probably assist in breathing (3, 98, 101, 102, 206).

Habits.—These insects usually occur under stones or in damp earth; in their manner of life they resemble the Springtails, but as a rule they are more active and lively. Several species are found in human dwellings, and one is especially partial to bakers' ovens. The sea-shore and the depths of caves are alike inhabited by insects of this order.

The Thysanura may be divided into two sub-orders.

SUB-ORDER A. ENTOTROPHI.

In this sub-order are included two families of Bristle-tails whose jaws (like those of the Collembola) through a deep inpushing at the mouth (213) seem sunk in the head, and whose bodies are not scaled.

Campodeidæ. — The *Campodeidæ* contain only two genera of small, delicate, white, blind springtails readily distinguished by their long many-jointed feelers and cercopods. There are three pairs of air-openings on the thorax, the tubular system from each remaining distinct. The small abdominal limbs are present on all the segments from the second to the seventh. A remarkable structural feature is the persistence of the tritocerebral appendages (see p. 93) as paired tubercles in the adult (103). The ovaries in the female are very primitive, consisting of paired, simple tubes, one along either side of the body (101, 102). These fragile insects have an exceedingly wide geographical range, occurring both in temperate and tropical countries, at the summit of snow-clad mountains and in the depths of caves (see fig. 65).

Iapygidæ.—The *Iapygidæ* are a family comprising only one genus (*Iapyx*). These insects are peculiar among the Thysanura, in the modification of their tail-appendages into forceps—like those of earwigs—instead of into cercopods. The small abdominal limbs present on each segment from the first to the seventh are less developed than in Campodea. There are eleven pairs of stigmata, and the air-tubes on either side of the body form a connected system. The species of Iapyx are unknown in our islands, being characteristic of the tropical and warmer temperate regions.

SUB-ORDER B. ECTOTROPHI.

This sub-order includes two families of Bristle-tails, with scaled bodies, and with jaws not withdrawn into the head, but articulated somewhat as in the cockroach, the maxillæ bearing prominent palps.

Machilidæ.—The *Machilidæ* are another family with only a single genus (*Machilis*). These insects have compound eyes largely developed, meeting in the central line of the head; in front of each compound eye is a peculiar elongate simple eye. In the hind-body the tergites overlap the sternites at either side, and limbs are present on all the segments from the second to the ninth inclusive. There is a prominent ovipositor in the female, while the long paired cercopods are exceeded in length by a similar median appendage borne on the tenth abdominal segment. There are nine pairs of air-openings; the tubes arising from these do not unite with each other. The Machilidæ are world-wide in their distribution.

Lepismidæ.—The *Lepismidæ* are the only family of Thysanura containing several genera. The eyes are less developed than in the Machilidæ, but the thoracic segments are larger than, and markedly distinct from, the abdominal; while the air-tubes, arising from ten pairs of stigmata, are united into one system by longitudinal and transverse connections, as in higher insects. The tergites of the hind-body do not overlap the sternites, and abdominal limbs are present only on the eighth and ninth segments. A many-jointed median tail-appendage is present as in Machilis, its length usually equalling that of the paired cercopods. The family has a most extensive geographical range. *Lepisma saccharina* (fig. 92), the "silver-fish insect," is a well-known inhabitant of houses.

ORDER 3.—DERMAPTERA.

Structure.—The EARWIGS are often included in the next order (Orthoptera) with which they agree in the structure of their jaws. They differ markedly, however, in their wings. Of these the front pair are modified into firm oblong plates serving as covers for the hind pair when at rest. The hind-wing of an earwig consists of an ovoid basal piece of firm texture, whence radiate numerous nervures supporting the spreading delicate membrane of the wing. This

membrane by a fan-like radial closing and two transverse folds can be tucked away beneath the firm basal piece, which is itself hidden under the forewing, its tip only projecting. A very large number of Earwigs, however, have the wings reduced to mere vestiges or entirely absent.

The tail-forceps are very characteristic organs of Earwigs, such appendages being unknown in any other insects save the Iapygidæ (described above). They are developed from the limbs of the eleventh abdominal segment in the embryo, which, as usual, is fused with the tenth in the adult. The forceps of male earwigs are usually longer and more complex than that of the female. In some genera the two limbs of the forceps are not symmetrical, one partially overlapping the other.

Fig. 93. — Common Earwig (*Forficula auricularia*, Linn.) Europe. Magnified.

The most important character of Earwigs is the nature of their genital ducts, which are entirely mesodermal in origin, and not formed partially by an ectodermal in-pushing, as in the Orthoptera and almost all other insects. In the genus Labidura the male ejaculatory ducts are paired; in Forficula these ducts are primitively paired, but one disappears in the course of growth, the other taking up, secondarily, a median position (49).

Development and Habits.—Earwigs undergo no transformation in their growth, the young being usually hatched in a state closely resembling that of the adult. It has lately been shown, however, that a Ceylonese earwig (106) is hatched with long jointed cercopods, like those of Campodea, which

at the last moult are transformed into the forceps. Earwigs pass much of their time under stones and in other concealed situations; their flattened bodies enable them to retire into small crevices. They feed on various vegetable substances—flowers, fruit, and leaves; but, at times, they attack and devour other insects.

The order Dermaptera contains but a single family,[1] the *Forficulidæ*, in which some 400 known species are comprised, distributed among numerous genera (**3, 104 a, 105**). Earwigs are most numerous in the tropics, but they are represented in all parts of the world.

ORDER 4.—ORTHOPTERA.

Structure.—In this Order, several families of insects are included which differ considerably in the details of their structure. All agree, however, in the possession of biting jaws, like those of the Cockroach, the second pair of maxillæ being incompletely fused together. The three thoracic segments are easily distinguishable. There are ten evident segments in the hind-body, the last bearing a pair of cercopods. The wings are characteristic in form, the front pair being of firm texture and serving as covers for the more delicate hind pair which can be folded fan-wise beneath them. The neuration in both fore and hindwings is complex. Four principal longitudinal nervures can be recognised on each forewing—the sub-costal[2] near the costa, the radial, the median, and the anal[3]—in the hindwings there is also an ulnar nervure, between the radial and median. From the principal nervures branches arise, and a number of short cross nervules connect these. The anal area, be-

[1] Unless the Hemimeridæ (see below under Orthoptera) should be included in this order.

[2] Or mediastinal.

[3] Or dividens.

hind the anal nervure, is much more extended in the hindwing than in the forewing, and is the part which undergoes fan-like folding when the wings are closed.

Though comparatively lowly insects, several families of Orthoptera are distinguished by the possession of complex sound-producing and hearing organs. All members of the order are hatched in a form closely like that of their parents. It has been estimated that there are at least 10,000 species of Orthoptera which are distributed among seven families (**3**, **107**).

Hemimeridæ.—The *Hemimeridæ* form one of the smallest families among insects; only one genus, with two species, is known. They are blind, wingless insects, somewhat like Cockroaches, with short, flattened legs and long cercopods. In the form of the head and body, however, these insects resemble Earwigs, and it is possible that they should be grouped with the Dermaptera rather than with the Orthoptera. Their development is most peculiar; the eggs are hatched within the body of the mother and the young are born one at a time, after having grown to a considerable size. The two species of *Hemimerus* inhabit West Africa. One of them is known to live among the hairs of a large rat, and is believed to prey on its external parasites (**108**).

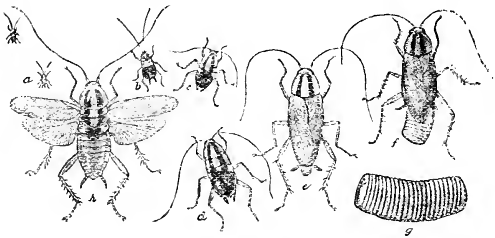


FIG. 94.—Cockroach, *Phyllodromia germanica* (Linn.) Europe. *a. b. c. d.* successive stages of young; *e.* male; *f.* female expelling egg-case; *h.* female with spread wings, natural size; *g.* egg-capsule, twice natural size. From Riley, Insect Life, vol. 2 (U.S. Dept. Agr.).

Blattidæ.—The *Blattidæ* or COCKROACHES are characterised by their flattened form, and wide pronotum beneath which the head, carried with the forehead downwards, is usually concealed. The coxæ of

the legs are extremely large and powerful, these insects running very swiftly. The eggs are contained in a purse-shaped capsule. Wings are usually present, but are often vestigial or absent. Cockroaches live in concealed situations among leaves, or beneath stones or bark, where they lurk during the day, coming out to feed at night, on all kind of substances. They are abundant in tropical countries, but become rare in the north, though several species which frequent houses and ships—*Blatta orientalis*, *Phyllodromia germanica* (fig. 94) and *Periplaneta americana*—for example, have been carried to all parts of the world.

Mantidæ.—The *Mantidæ* or "PRAYING INSECTS" are easily recognised by the possession of a very long prothorax, and a pair of powerful front legs adapted for seizing prey. These limbs have elongate haunches, and the thighs and shins bear formidable spines on their inner edges. The head is readily movable, being joined to the forebody by a flexible neck; it is broad from side to side, the prominent compound eyes being widely separated; three simple eyes are present above and between the slender feelers. The wings are more highly modified than those of Cockroaches, the costal area —in front of the sub-costal nervure—of the forewings, and the anal (folding) area—behind the anal nervure—of the hindwings being especially large. The cercopods, as in cockroaches, are many-jointed. Female Mantids enclose their eggs in curious cases; these are formed by the action of the tips of the forewings out of a sticky secretion which hardens after exposure to the air. The egg-case is attached to a twig or stone, and contains numerous chambers, wherein the eggs lie. After leaving their chambers, the young Mantids hang from the egg-case by threads attached to the cercopods, until after the first moult.

Mantids are sluggish in their motions, creeping stealthily on their prey (small insects, etc.) till within striking distance, when the victim is suddenly seized by the spiny fore-legs. The bodies and wings of Mantids are usually green, agreeing closely in colour with the plants whereon they live; in some cases the prothorax, and the legs of the two hind pairs are flattened and leaf-like. These insects are numerous in all tropical countries, but are absent from cooler regions; only a dozen species represent the family in southern Europe (**109 b**).

Phasmidæ.—In the *Phasmidæ* the mesothorax, and not the prothorax, is the longest segment of the forebody. The three pairs of legs are all closely alike; the cercopods are not jointed, each consisting of a single flattened piece. The forewings are usually very much reduced, while the hindwings are often extensive, with large delicate anal area, capable of fan-like folding beneath the firmer front portion of the wing; frequently, however, both pairs of wings are reduced to mere scales, or entirely wanting, especially in the females, which are often larger than their mates. The bodies of Phasmids are, as a rule, greatly lengthened, and the legs long and

slender; the insects bear a wonderful likeness to the twigs and branches of trees, and are familiarly known as "walking sticks." In some Indian Phasmids, however—the "leaf-insects" (*Phyllium*)—the body and leg segments are flattened into leaf-like plates. In the male the forewings are very small, while the hindwings are developed; but in the female the hindwings are greatly reduced, while the forewings are large and leaf-like, with an immense rounded costal area in front of the radial nervure, the anal nervure being close to the dorsum of the wing. Phasmids are sluggish in their habits, but devour greedily the leaves of the plants whereon they feed. The eggs are enclosed singly in curiously shaped capsules resembling seeds. The geographical range of Phasmids is similar to that of Mantids (**109 a**).

The insects of the three remaining families of Orthoptera are all characterised by the possession of very long and strong hind-legs modified for jumping. They are remarkable in having very perfect ears, and (the males especially) stridulating organs which produce chirping sounds.

Locustidæ.[1]—The *Locustidæ*, comprising the familiar Grasshoppers, migratory Locusts and their allies, are distinguished from the two succeeding families by short feelers which never have more than thirty segments, and by the ovipositor in the female not projecting far beyond the end of the hind-body. There are three tarsal segments. These insects are provided with an ear situated on either side of the first segment of the hind-body; this organ has already been described (p. 45). The male locustids make a chirping sound by scraping rows of pegs on the inner edge of the hind thighs over the sharp edge of the nervures of the forewings. The forewings are long and narrow, the hindwings ample, the folding anal area being largely developed. The insects of this family (see fig. 63) live entirely on vegetable substances; certain species multiply at times into enormous swarms, which commit great damage on the crops in warm countries. The females, with their short stout ovipositors, dig holes in the ground wherein to lay their eggs, covering them with a fluid secretion which hardens into an irregular capsule. The Locustidæ are the most numerous of all the orthopteran families, and are met with in all parts of the world.

Phasgonuridæ.[2]—The *Phasgonuridæ*, including the long-horned or tree grasshoppers, are readily distinguished from the preceding family by the possession of long, slender feelers made up of many more segments than thirty, and often much longer than the body. The ear (described on p. 43) is situated at the base of the foreshin, and there are four tarsal segments to each foot. These insects produce a shrill chirping note by the friction of a transverse file

[1] *Acridiidæ* of most authors. [2] *Locustidæ* of most authors.

beneath the base of the left forewing over a sharp ridge on the dorsum of the right. They frequent trees and live for the most part on leaves, though some species are known to devour other insects. The female's ovipositor is long and prominent, sometimes as long as the body; by means of it she buries her eggs in the ground for safety. The forewings of Phasgonurids are, as a rule, relatively less narrow than those of Locustids; in some tropical genera they are convex in outline, both in colour and neuration closely resembling leaves. Wingless forms are not uncommon. The insects of this family are abundant in the tropics, but become rare in cooler regions; several species, however, are found in our islands.

Gryllidæ.—The *Gryllidæ*, or Crickets, are closely allied to the preceding family, which they resemble in having long feelers and ovipositors; in many species the abdominal cercopods are also very long. The ears have the same situation as in the Phasgonurids, and the chirping organs are also similar, except that there is a stridulating file under each forewing. The forewings are remarkable in structure, the anal area lying flat over the body, while the rest of the wing when at rest is turned downwards at the side of the insect. The hindwings are often longer than the forewings, as well as broader, and project beyond the tips of the latter when rolled up. Wingless forms, however, are not uncommon. Most Crickets are vegetable-feeders, but the Mole-Crickets (Gryllotalpa), characterised by their broad and powerful digging fore-legs and short ovipositors, are largely carnivorous. Crickets are found in all parts of the world, the House-cricket (*Gryllus domesticus*, fig. 95) being one of the most familiar of domestic insects.

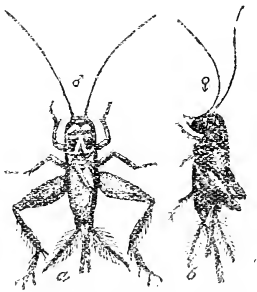


FIG. 95.—Cricket (*Gryllus domesticus*, Linn.) Europe. *a.* male; *b.* female. Natural size. From Marlatt, Bull. 4 (n.s.) Div. Ent. U.S. Dept. Agr.

ORDER 5.—PLATYPTERA.

This order has been founded (97) for the reception of several families of the old Neuroptera, characterised by the possession of biting jaws, the mandibles being

always well developed (fig. 98), and by the absence of a metamorphosis. The wings, when present, are

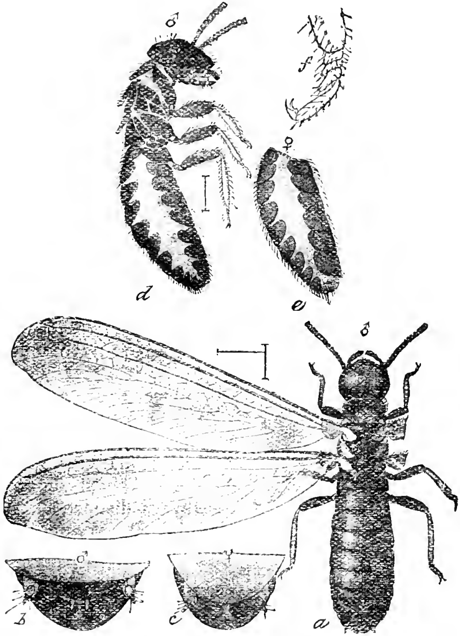


FIG. 96.—*Termes flavipes*, Kol., North America. *a*. male, from above; *d*. from side with wings removed; *e*. hind-body of female from side, magnified 8 times; *f*. end of shin and foot, magnified 40 times; *b*. hinder segments of male abdomen from beneath; *c*. of female, magnified 24 times. From Marlatt, Bull. 4 (n.s.) Div. Ent. U.S. Dept. Agr.

net-veined. A further sub-division of this group has

been suggested, the Stone-flies being reckoned as a distinct order by some naturalists (96). They are here treated as a sub-order, which must be regarded as not very nearly related to the other two sub-orders recognised.

SUB-ORDER A. MALLOPHAGA.

Structure.—This division includes the "Biting-lice." They are wingless insects with elongate flattened body and large head. The feelers are short with only three to five segments, and the eyes very degraded or altogether absent. The mandibles are provided with sharp teeth, but the first pair of maxillæ are reduced to conical lobes; the second maxillæ are fused together to form a broad plate-like lower lip. The prothorax is always distinct, but the other two segments of the fore-body are usually very small, the metathorax being often united with the hind-body, which consists of from eight to ten visible segments (3, 110).

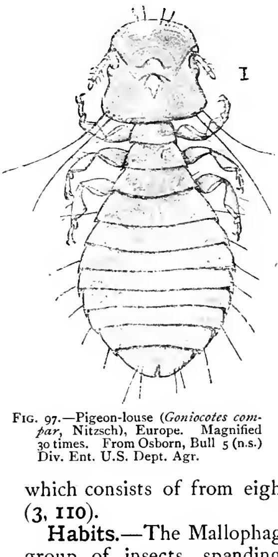


FIG. 97.—Pigeon-louse (*Goniocotes compar*, Nitzsch), Europe. Magnified 30 times. From Osborn, Bull 5 (n.s.) Div. Ent. U.S. Dept. Agr.

Habits.—The Mallophaga are entirely a parasitic group of insects, spending their lives among the plumage of birds or the fur of mammals, and feeding

on the delicate parts of the feathers or hairs, as well as on the dried secretions of the skin. Their flattened, wingless bodies are well adapted for such a life. The eggs are attached to the feathers or hairs of the host, and the young very closely resemble their parents.

Two families of Mallophaga are recognised, comprising about 1000 known species (**111**).

Liotheidæ.—The *Liotheidæ* are characterised by the presence of four-segmented palps on the second maxillæ, and long two-segmented and two-clawed tarsi on the legs. They are fairly active insects, and when their host dies, they are able to go in search of another. Most of the species live on birds, but many are attached to mammals.

Philopteridæ.—The *Philopteridæ* are more degraded than the Liotheidæ. The second maxillæ are destitute of palps; the tarsal segments are very short, and opposable to the shin, so that the insect clings by its feet to the feathers of the host. With the exception of a single genus, the Philopteridæ (fig. 97) are all found on birds. They are incapable of travelling from one bird to another, and perish soon after the death of their host.

Both families of Mallophaga are world-wide in their distribution.

Sub-Order B. Corrodentia.

This sub-order includes insects readily separable from the Mallophaga by the possession of fairly long feelers—with ten or more segments; and by the absence of the degradation in structure which accompanies parasitism. They are terrestrial throughout life.

There are three very distinct families which may be considered separately.

Embiidæ.– The *Embiidæ* are small insects of elongate form. The feelers have from fifteen to twenty-four segments; while the jaws resemble those of Orthoptera, the maxillæ of the second pair being imperfectly fused together. The prothorax is small, the other two segments of the fore-body are long and similar to each other; the hind-body has ten evident segments whereof the hindmost bears a pair of two-segmented cercopods. The wings of the two pairs (when present) are closely alike; each wing has four longitudinal nervures, the second and third of these only reaching the wing-tip, and being connected by a few cross-nervules. There are three tarsal segments; the proximal segment on the front foot is provided with glands whose secretion forms a silken thread, which is woven into

tunnels or galleries of web wherein the insects live. They feed on vegetable matter. Only about twenty species are known, and the family is confined to the warmer regions, ranging north only to Southern Europe and the Atlantic Islands (**3, 112, 113**).

Termitidæ.—The *Termitidæ* are in many respects like the Embiidæ, but are not so narrow and elongate in form. The head is large and may be provided with compound eyes and two simple eyes, but many forms are quite blind. The number of antennal segments varies between nine and thirty-one. The maxillæ of the second pair are joined together, but a median channel marks the line of their fusion. There are three distinct thoracic and ten abdominal segments, the hindmost, with a pair of short cercopods of several joints (fig. 96 *b*, *c*). The wings of the two pairs are closely alike, each is provided with three principal longitudinal nervures—the sub-costal, median, and sub-median, which give off many branches. The most characteristic feature of Termites' wings, however, is

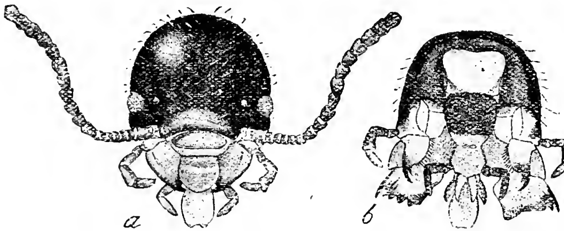


FIG. 98.—Head of Termite. *a*. ront view; *b*. back view, showing jaws. Magnified 20 times. From Marlatt, Bull. 4 (n.s.) Div. Ent. U.S. Dept. Agr.

the presence of a transverse suture or line of weakness close to the root. After flight the wings are shed by a rupture at this suture (fig. 96 *a*, *d*).

Termites live together in large social communities which consist of "kings" and "queens"—fertile males and females which after the nuptial flight have cast their wings—and infertile males and females ("soldiers" and "workers") in which wings are never developed. They feed on wood and waste substances, and construct earthern tunnels and galleries, often forming large nests. The "queen" termite, with her enormously swollen abdomen, whereof the segmental sclerites become widely separated by vast tracts of membrane, is one of the most remarkable of insects (see fig. 178). Termites are confined to the tropical and warmer temperate regions, being quite unknown in these countries (**3, 113**).

Psocidæ.—The *Psocidæ* are small soft-bodied insects. The head

is large and bears a pair of very slender many-jointed feelers (eleven to over twenty segments), and prominent eyes. The prothorax is

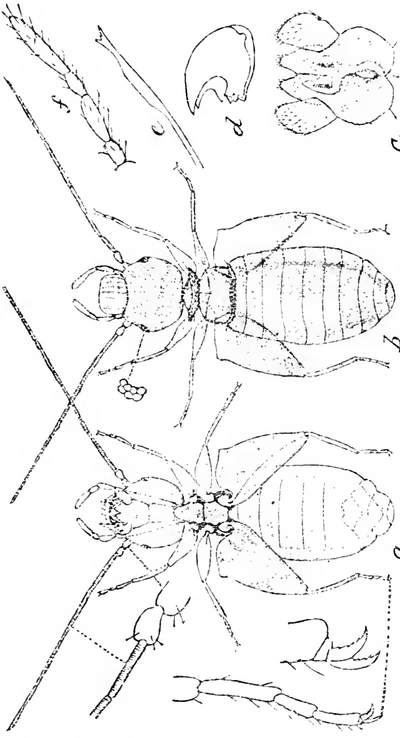


FIG. 99.—Book-louse (*Atropos divinatoria*, Fab.), Europe. *a.* from below; *b.* from above, magnified 50 times (eyes, feeler, feet, and claws, more highly magnified); *c.* 2nd maxillæ; *d.* mandible; *e.* blade or "pick" of 1st maxilla; *f.* its palp, highly magnified. From Marlatt, Bull. 4 (n.s.) Div. Ent. U.S. Dept. Agr.

very small, the mesothorax and metathorax large; there are ten abdominal segments, but no cercopods. When wings are present

the front pair are considerably the larger; four nervures can be traced, corresponding with those of the Termitidæ, but their tortuous course, forming several irregular "cells," contrasts with their comparatively rectilinear arrangement in that family. The best-known of the Psocidæ—the familiar "booklice" are wingless (fig. 99). Many species are found on trees and they feed on all kinds of waste substances. The largest Psocid known measures only an inch across its outspread wings. The family ranges over all parts of the world (3).

Sub-Order C. Perlaria.

Structure.—The Stone-flies, which make up this sub-order, are distinguished from the two preceding groups of Platyptera by the dissimilarity of the wings of the two pairs, which resemble in form those of Orthoptera, the front pair being long and narrow, the hind pair broad with a large anal area folding fan-wise. Both pairs, however, are alike membranous in texture; the reticulation is very complicated, a large number of cross nervules, at various angles, intervening between the four principal longitudinal nervures and their branches. The wings of the male are often much reduced and useless for flight. The head is broad and carries a pair of long, many-jointed feelers; the jaws are feeble, but the usual three pairs are evidently present. The prothorax is broad and free, the other two segments of the fore-body distinct and equal to each other. The haunches are small, and the two legs of each pair widely separated. There are ten evident segments in the hind-body, the last usually bearing a pair of long, many-jointed cercopods.

Development and Habits. — In their development the Stone-flies differ markedly from the Mallophaga and Corrodentia; the nymphal stages are passed under water, the nymphs whose tracheal system is closed, breathing the dissolved air either through the skin or by means of tufted gills, which may still be

found, though in a reduced condition on the perfect insects. The nymphs closely resemble their parents in form; they are most commonly found in swift streams, and they feed on smaller water-insects, such as Mayfly-grubs. The imagos are usually to be observed near the water whence they came (170).

The Perlaria include only a single family—the *Perlidæ*, with a world-wide distribution (3, 114, 115). By many naturalists they are regarded as a distinct order—Plecoptera (96).

ORDER 6.—THYSANOPTERA.

Structure.—The Thysanoptera are a restricted order of small insects with elongate bodies, jaws which serve for suction with comparatively little modification, and narrow, fringed wings. The head is elongate and flat with the face sloping backwards; compound eyes are always present, and usually three simple eyes also. The feelers have from six to nine cylindrical or beadlike segments. The mandibles are needle-like piercers hidden in a conical beak which is formed by the fusion of the upper lip and the two pairs of maxillæ, and lies in a cavity of the prosternum; the palps of both pairs of maxillæ are present, those of the first having two or three segments, those of the second two or four. The epipharynx is developed as a piercing stylet lying

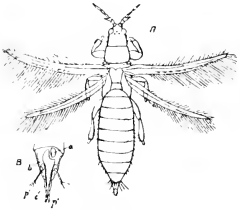


FIG. 100.—*A. Limothrips denticornis*, Hal., Europe. Magnified 10 times. *B.* Jaws of *Poecilothrips albopicta*, Uzel. Magnified 16 times. *a.* epipharynx; *b.* 1st maxilla; p^1. its palp; *c.* 2nd maxilla; p^2. its palp. After Uzel, "Monogr. Thysanoptera."

asymmetrically to the left side within the beak. The prothorax is large and free, the other two segments of the fore-body partially fused together. The legs are short, and the feet have only one or two segments which bear two minute claws and a prominent bladder-like sucker. The wings of the two pairs are long, narrow, membranous, with very few nervures, and fringed with long hairs; the forewings are somewhat longer than the hindwings, and rather firmer in texture; in several genera wings are wanting. Ten abdominal segments are present, the last of which is often tubular (fig. 100) (**116**).

Life-history and Habits.—The young nymphs when hatched are closely like the adult in form, but soft-skinned and of course without wings. In the stage before the final change the nymph is sluggish, its limbs obscured by a film, and the wing-rudiments enclosed in sheaths: in some cases it is said to be immovable and to take no food. The development of the Thysanoptera therefore exhibits an interesting transition towards a true metamorphosis. The insects live, often in great numbers, on the leaves and flowers of plants whence they suck the sap; also under bark. They are probably of general distribution, but have hardly been studied beyond the limits of Europe and North America. The order is divided into three families. Less than 200 species are known (**116**).

Æolothripidæ.—The *Æolothripidæ* have nine-segmented feelers; the forewings have a costal nervure around the whole margin, and two longitudinal nervures. In the female an ovipositor is developed from four processes on the eighth and ninth abdominal segments; this organ when extended is curved backwards.

Thripidæ.—The *Thripidæ* agree with the preceding family in wing-neuration and in the presence of an ovipositor in the female; but this organ is curved downwards instead of backwards, and the feelers have only eight segments.

Phlœothripidæ.—The *Phlœothripidæ* are distinguished by the

entire absence of wing-nervures, or at most only a single short longitudinal nervure is present. The feelers have eight segments. The body is flat, and the last abdominal segment is always narrowly cylindrical.

ORDER 7.—HEMIPTERA.

Structure. — The Bugs, Lice, Cicads, Froghoppers, Plant-lice and Scale Insects which

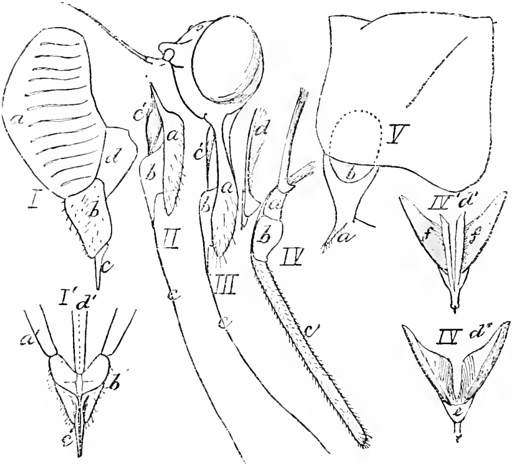


Fig. 101.—Head and prothorax of Cicad from side, parts separated. I. *a.* face; *b. c.* upper lip; *d.* epipharynx (I'. same from behind). II. Mandible. III. 1st maxilla; *a.* base; *b.* sheath; *c.* stylet; *c'.* muscle. IV. 2nd maxillæ; *a.* sub-mentum; *b.* mentum; *c.* ligula, forming beak; *d.* hypopharynx (shown also from front *d'.*, and behind *d''.*). V. Prothorax; *b.* haunch; *a.* trochanter. From Marlatt, Bull. 14 (n.s.) Div. Ent. U.S. Dept. Agr.

make up this order are characterised by having highly developed sucking and piercing jaws. The mandibles and first maxillæ are transformed into

stylets, often barbed towards the tip; these work to and fro within the groove of a stout-jointed beak (*rostrum*) which is formed by the union of the second maxillæ (fig. 101). The head is usually triangular in shape; the slender feelers have from three to eight segments. The prothorax is free, its tergite (pronotum) always being well-developed; the legs and wings vary considerably in the different sub-orders. The hind-body usually has nine evident segments whereof the last three are often modified for reproduction; genital stylets in the males, and ovipositors in the females, are often present.

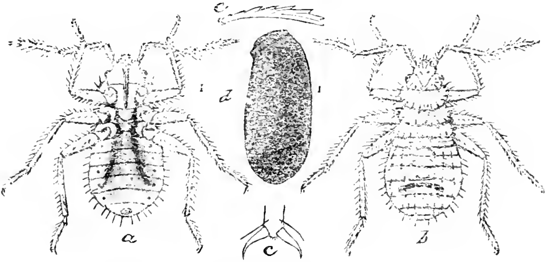


FIG. 102.—*a*. Bed-bug (*Cimex lectularius*, Linn.) newly hatched, from beneath; *b*. from above; *d*. egg, magnified 25 times; *c*. foot of nymph with claws; *e*. serrate spine, more highly magnified. From Marlatt, Bull. 4 (n.s.) Div. Ent. U.S. Dept. Agr. (Compare fig. 104).

The Hemiptera are divided into three well-marked sub-orders characterised by differences in the form of the wings, and in the nature of the life-history.

SUB-ORDER A. HETEROPTERA.

The **Heteroptera** or BUGS are distinguished by the modification of the forewings into partially horny covers for the entirely membranous hindwings. The scutellum of the mesonotum is always a prominent

feature; the hard part of the forewing next to this, when the wings are closed, is the *clavus;* this is divided by a suture, running parallel to the edge of the scutellum, from the *corium*, another hardened area which in most families reaches to the costa, but in one is separated from that edge by a narrow *embolium*. Beyond the corium in some families comes the small triangular *cuneus*, another hardened area towards the costa; beyond corium and cuneus is the transparent membranous area which reaches to the tip of the wing, and shows a simple neuration varying in the different families. The young Heteroptera, as hatched from the egg (fig. 102), closely resemble their parents except for the absence of wings, of which rudiments appear as growth proceeds. The sub-order, including about 7000 known species, is divided into several families (**117, 118, 119, 120**).

Pentatomidæ. The *Pentatomidæ* or Shield-bugs are characterised by the great development of the scutellum, which always reaches back to the base of the membrane, and, in some genera, completely covers the folded wings. The head is acutely triangular with thin leaf-like margins; the feelers have five segments. The forewing has three areas—clavus, corium and membrane, and the foot has two or three segments. The Shield-bugs (fig. 103) live on plants whose juices they suck; they are very abundant in the tropics, and are represented in all parts of the globe. Many are brightly coloured.

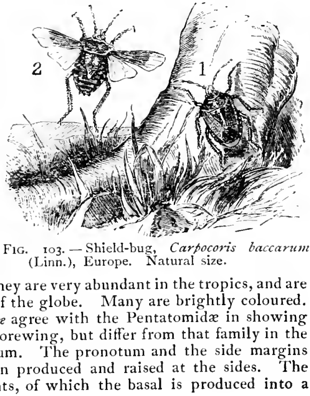


Fig. 103.—Shield-bug, *Carpocoris baccarum* (Linn.), Europe. Natural size.

Coreidæ.—The *Coreidæ* agree with the Pentatomidæ in showing only three areas in the forewing, but differ from that family in the relatively smaller scutellum. The pronotum and the side margins of the hind-body are often produced and raised at the sides. The feelers have four segments, of which the basal is produced into a

tubercle laterally, and the terminal is club-shaped; they are inserted high up on the head. The membrane of the forewing is traversed by several longitudinal nervures. The bugs of this family live by sucking the juices of plants, and have as wide a range as the Pentatomidæ.

Berytidæ.—The *Berytidæ* are a small family of bugs which share most of the structural features of the Coreidæ, but are distinguished by their slender form and very long feelers and legs. The basal segment of the feelers, and the thighs are clubbed at the tip.

Lygæidæ.—The *Lygæidæ* are a very large family of bugs. The four-segmented feelers are inserted lower on the head than in the Coreidæ. As in that family there are three tarsal segments, and the beak when in repose lies against the lower surface of the head. Two ocelli are present except in the large sub-family Pyrrhocorinæ. The membrane of the forewing has not more than five nervures; the only hardened areas, as in the preceding families, are the corium and clavus. The bugs of this family are plant-feeders, and are distributed in all parts of the world.

Tingididæ.—The *Tingididæ* may be distinguished from the preceding families by the presence of only two tarsal segments instead of three, as well as by the remarkable net-like puncturation of the upper surface of the body and of the forewing, in which the clavus is usually wanting. The second segment of the feeler is very short, and the third very long. The base of the pronotum is usually produced backwards so as to cover the scutellum, and the front legs are inserted in the hind margin of the prosternum.

Aradidæ.—The *Aradidæ* agree with the Tingididæ in their two-segmented feet, but the surface is not similarly punctured; the pronotum does not cover the scutellum which is large, and the front legs are inserted midway on the prosternum. The family is small, containing but few genera.

Hebridæ.—The *Hebridæ* are a small family of tiny bugs, living in pond-weed, bog-moss, and similar damp situations, in correspondence with which their hind-body is covered with short hairs forming a thick velvety pile. The feelers are five-segmented, and inserted far in front of the eyes and rather low on the sides of the head, and the feet are ten-segmented. The family contains but a single genus (*Hebrus*).

Hydrometridæ.—The *Hydrometridæ* or PONDSKATERS are another large family of bugs which live for the most part on the surface of water. Like the Hebridæ they have a velvety pile on the hind-body, but there are only four antennal segments. There may be two or three tarsal segments. The forewings are peculiar in not showing divisions into the areas—corium, clavus, etc., usual in the sub-order; they are traversed by a simple system of nervures. The insects of this family feed on smaller aquatic creatures, or on floating waste-material. They are distributed throughout the world, and several genera are marine (170, 171).

Reduviidæ.—The *Reduviidæ* are distinguished from the preceding families by the short bent beak, which does not lie close beneath the head when not in use. The feelers are slender, the eyes prominent and placed far in front of the pronotal margin, and the ocelli situated behind the eyes. The front thighs are usually thickened. When developed the forewing is divisible into corium, clavus, and membrane. These bugs are mostly of large size and prey on smaller insects; they are abundant in tropical countries, but become scarcer in cooler regions.

Saldidæ.—The *Saldidæ* are a small family of bugs, whose beak, as in the Reduviidæ does not lie closely beneath the head, though it is relatively longer than in that family. These insects are oval in shape, rather convex above: the feelers are slightly thickened at the tip, and the ocelli are placed between the eyes. The side edges of the pronotum are keeled. The forewing is composed of corium, clavus and membrane, but the outer margin of the corium is rounded. There are three tarsal segments. The Saldidæ live in damp places, especially in salt marshes.

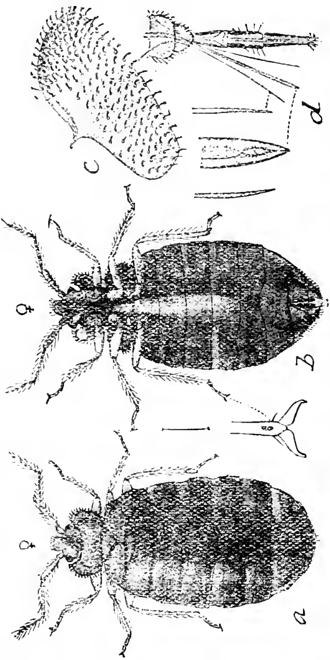


FIG. 104.—Bed-bug (*Cimex lectularius*, Linn.). *a.* emale from above; *b.* from beneath, magnified 5 times; *c.* vestigial wing; *d.* jaws, more highly magnified (tips of mandibles and 1st maxillæ still more highly magnified). From Marlatt, Bull. 4 (n.s.) Div. Ent. U.S. Dept. Agr.

Cimicidæ.—The *Cimicidæ* are small bugs, distinguished from the

preceding families by the presence of a cuneus and an embolium in the forewing, as well as of corium, clavus, and membrane. The face is prolonged forwards in front of the bases of the feelers; its edges are straight and usually parallel. Ocelli are present except in the best known genus of the family—*Cimex* (forming the sub-family *Cimicinæ*) which includes the common Bed-bug (fig. 104); in this genus, moreover, the forewings are reduced to small pads (fig. 104 *c*). There are four segments to the feelers and usually three to the feet; but in one sub-family (*Microphysinæ*), the feet have only two. In the sub-family *Ceratocombinæ* the feelers are very long and thin, and bear many long hairs; the two terminal segments are together twice the length of the two basal. In the sub-family *Anthocorinæ*, which contains the majority of the genera, the feelers are of the usual form. The Cimicidæ occur on plants, in waste material, under bark and in like places, and are universally distributed.

Capsidæ.—The *Capsidæ* are an exceedingly large family of rather small-sized bugs, distinguished from the Cimicidæ by having no embolium, and from all the other families by having a cuneus in the forewing. The skin is softer than in most other bugs, and the form of the body is usually elongate and the surface slightly convex, though in structural details there is the greatest diversity among the very numerous genera into which the family is divided. The feelers are four-segmented, the two basal segments being almost always stouter than the two terminal; the feet are three-segmented. The male has genital armature visible on the dorsal aspect of the hindmost abdominal segment; the female has a distinct ovipositor beneath the last two or three segments. The Capsidæ are abundant on plants whose juices they suck. They are found in all parts of the world.

In the four remaining families of Heteroptera, the feelers are very small and hidden in cavities beneath the head. They are typically aquatic insects, diving and swimming through the water (**170**).

Naucoridæ.—The *Naucoridæ* are a small family of water-bugs, characterised by four-segmented feelers and by the insertion of the fore-legs far forward on the prosternum. The head is deeply sunk in the front edge of the pronotum. The front thighs are flat and wide; the front feet either with two segments and clawed, or with one segment and no claws; and the hind-feet with two segments and two distinct claws. The Naucoridæ are broadly oval in form, and live in ponds and streams.

Nepidæ.—The *Nepidæ* are a family of large water-bugs with the front legs inserted as in the Naucoridæ, but with three-segmented feelers. They may be recognised at once by the long tail-processes which serve as a breathing organ (see p. 291). The feet are all

one-segmented; those of the middle and hind pairs bear two claws. Those of the front pair are clawless, curved, and sharp, the powerful forelegs being modified for seizing prey, as the Nepidæ feed on smaller inhabitants of the water. Only two species inhabit our islands — one (*Nepa* the "water-scorpion") has a broad and flat body, while the other (*Ranatra*) is very long and narrow. Some tropical Nepidæ attain a gigantic size.

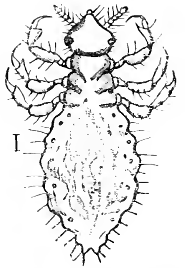


FIG. 105.—Louse (*Pediculus vestimenti*, Leach) Europe. Magnified 15 times. From Osborn (after Denny), Bull. 5 (n.s.) Div. Ent. U.S. Dept. Agr.

Notonectidæ. — The *Notonectidæ* or "Water-boatmen" are distinguished from the Naucoridæ and Nepidæ by the insertion of their fore-legs at the hinder edge of the prosternum. The body is convex; the head large and broad with prominent eyes and four-segmented feelers, the beak short and conical with three or four segments; the scutellum large; the forewings well-developed and reaching to the tip of the hind-body; and the feet with two distinct segments.

Corixidæ.—The *Corixidæ* are a family of small water-bugs, distinguished by their elongate oval, flattened form and short unjointed beaks. The head is very wide, wider than the pronotum. The fore-legs are short and thick, the feet consisting of a single flattened segment, which bears, in the male, a row of small strong teeth; these drawn across the sharp edge of the face produce a shrill chirping note. The middle legs are long with one-segmented, clawed feet, and the hind-legs are also long, the feet being two-segmented and flattened and fringed so as to serve as oars. The hinder abdominal segments in the male are not symmetrical, and the sixth segment bears on its upper side a small stalked plate furnished with rows of teeth; this organ is called the *strigil*, but its function is unknown. The Corixidæ are distributed in all parts of the world.

SUB-ORDER B. ANOPLURA.

The **Anoplura** or true LICE (fig. 105) are small, parasitic insects, distinguished from all other Hemiptera by the absence of all vestiges of wings and the unjointed fleshy beak (fig. 106) which is provided with a circle of hooklets near the base, giving a firm hold

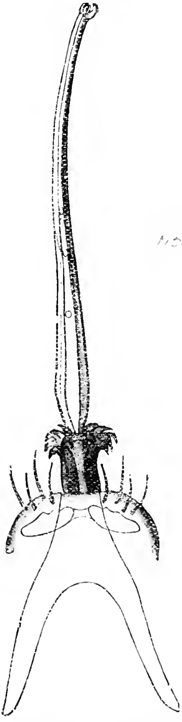


Fig. 106.—Jaws of *Pediculus vestimenti*. Highly magnified. From Osborn (after Schiodte), Bull 5 (n.s.) Div. Ent. U.S. Dept. Agr.

on the skin of the host, and with four tiny lobes at the tip. The Lice are insects of flattened form spending their whole lives on the bodies of mammals whose blood they suck. Three species are sometimes found on man. All lice may be included in a single family—the *Pediculidæ* (**111**).

not see page 149.

Sub-Order C. Homoptera.

The **Homoptera**, including the Cicads, Froghoppers, Plant-lice, etc., are readily distinguished from the Heteroptera by the slight differentiation of the forewings; sometimes these are firmer in texture than the hind-wings, but they never show distinct hard areas like those of the Heteroptera. When at rest the wings slope roofwise over the back, whereas in the Heteroptera, they lie flat. The sub-order is further distinguished by the backward slope of the face, which brings the beak into close contact with the front haunches (fig. 107). The feelers have one or a few basal segments thickened, the rest of the segments forming a thread-like ending. In the nature of the life-history the Homoptera show an advance on the Heteroptera; the young in several families are

true larvæ differing in form from their parents, and in one family (Coccidæ) there is a passive stage before the last moult, forecasting the pupa of the higher orders.

In the first six families the feet have three segments (**121**).

Cicadidæ.—The *Cicadidæ* (CICADS) are a family of (mostly) large

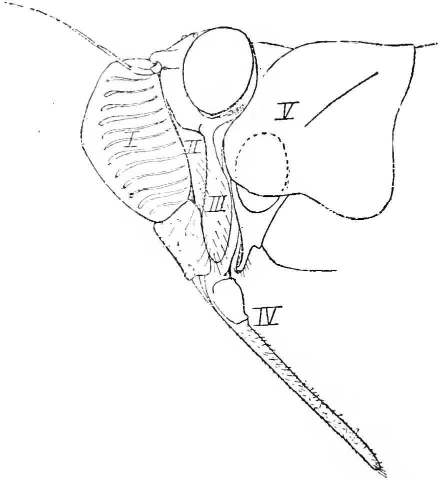


FIG. 107.—Head of Cicad from side. I. face; II. base of mandible; III. base of 1st maxilla; IV. 2nd maxillæ; V. pronotum. Magnified. From Marlatt, Bull. 14 (n.s.) Div. Ent. U.S. Dept. Agr.

insects distinguished from other Homoptera by the front thighs being thickened and toothed beneath. The head is broad with prominent compound eyes, and three simple eyes on the crown. The wings are large and powerful with a regular system of branching nervures and cells; the front pair are much larger than the hind pair. The abdomen tapers towards its hinder end (fig. 86). The male Cicads produce their well-known shrill song by the

rapid vibration of a drum or membrane within the metathorax; the cavities of these sounding organs are protected by large plates (fig. 108) which overhang the first abdominal sternite. The female Cicad, by means of her saw-like ovipositor, cuts slits in twigs of trees in order to lay her eggs therein. The young grubs with evenly-segmented feelers and large digging fore-legs (fig. 74) burrow underground and feed on roots for several years. In some species, before the final moult, they make cylindrical earthen dwellings (fig. 75) within which they passively await the change into the winged form. The family is very abundant in the tropics of both hemispheres (**123**), but only about thirty

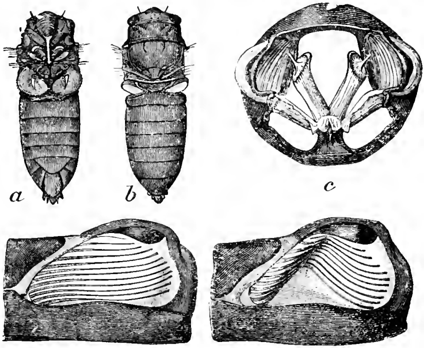


FIG. 108.—*a*. Body of male Cicad from beneath, showing cover-plates of musical organs; *b*. from above, showing drums, natural size; *c*. section showing muscles which vibrate drum (magnified); *d*. a drum at rest; *e*. thrown into vibration, more highly magnified. From Marlatt, Bull. 14 (n.s.) Div. Ent. U.S. Dept. Agr.

species reach the shores of the Mediterranean, and one the British Isles (**120, 121**).

Fulgoridæ.—The *Fulgoridæ* are characterised by three-segmented feelers inserted beneath the eyes; two ocelli are recognisable between the eyes, the third is usually vestigial or wanting. The head is large, in some genera produced forwards into a great bladder-like lobe as long as the body—as in the South American and Oriental "Lantern-flies." The pronotum is not produced into a process behind. The hind-legs are thick and long and serve for leaping. The forewings are of firmer texture than the

hind pair, and are frequently coloured while the latter are transparent. The family is generally distributed.

Cercopidæ.—The *Cercopidæ* are distinguished from the Fulgoridæ by the insertion of the feelers between, not beneath the eyes. There are two ocelli. The pronotum has an angular notch on the hind margin, and the scutellum is accordingly rhomboidal. The forewings are decidedly firm in texture, often clothed with fine, short hairs; the hind shins are cylindrical, each with a terminal row of spines, and with two spines on the outer side. The nymphs of our native species of this family (which is generally distributed) live on plants where they protect themselves by a frothy secretion—the well-known "cuckoo-spit."

Membracidæ.—The *Membracidæ* are characterised by the crown of the head being vertical (bearing two ocelli), so that the face looks almost directly downwards. The pronotum is produced behind into a long process. The hind-haunches are large and the thighs of the legs are triangular in section. The family is poorly represented in Europe (only two species inhabit the British Isles), but in tropical countries the species are numerous and often very remarkable in form on account of the striking development of the pronotal processes.

Iassidæ.—The *Iassidæ* are a very large family of small insects, together with the smaller species of the Cercopidæ known as "Frog-hoppers." They are distinguished from the Cercopidæ by the prismatic hind-shins and the triangular scutellum; from the Membracidæ by having no prosternal processes. The young nymphs are soft-skinned and often protect themselves by "cuckoo-spit." The family is of general distribution.

The four remaining families are distinguished from the six preceding by having only two tarsal segments.

Psyllidæ.—The *Psyllidæ* or "Jumpers" are a very large family of small insects. The feelers are long, with ten segments, the first two segments short and stout, the remainder finely thread-like, the terminal segment with two divergent bristles. The head is broad with prominent compound eyes and three ocelli. The legs are short with thick thighs, and the forewings are usually firm in texture. The family is widely distributed, and the species are very numerous on plants (121).

Aphidæ.—The *Aphidæ* or Plant-lice are a very large family of soft-skinned insects with feelers of five to seven segments, usually longer than the body, no ocelli, long slender legs, and delicate hyaline wings with few nervures. Often, however, the mature forms are wingless. A pair of tubes on the hind-body are usually present, through which a "honey-dew" secretion is discharged (fig. 109). The young aphids are closely like their parents; in most species active young are produced in great numbers through the summer

by unfertilised females; in autumn, eggs are laid by fertilised females; these are hatched in the ensuing spring (**122**).

Aleyrodidæ.—The *Aleyrodidæ* are a small family of tiny delicate insects in which both sexes have evenly rounded, white wings, each with only one median nervure. The feelers have six segments, whereof the second is lengthened.

Coccidæ.—The *Coccidæ* or SCALE-INSECTS are distinguished by the very striking difference between the sexes. The males have long

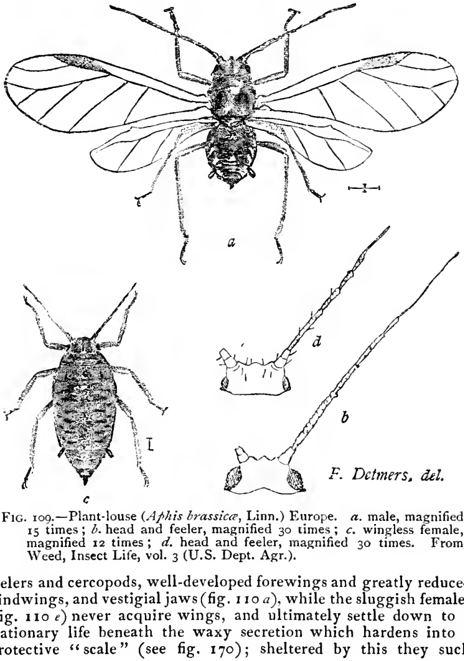


FIG. 109.—Plant-louse (*Aphis brassicæ*, Linn.) Europe. *a.* male, magnified 15 times; *b.* head and feeler, magnified 30 times; *c.* wingless female, magnified 12 times; *d.* head and feeler, magnified 30 times. From Weed, Insect Life, vol. 3 (U.S. Dept. Agr.).

feelers and cercopods, well-developed forewings and greatly reduced hindwings, and vestigial jaws (fig. 110 *a*), while the sluggish females (fig. 110 *e*) never acquire wings, and ultimately settle down to a stationary life beneath the waxy secretion which hardens into a protective "scale" (see fig. 170); sheltered by this they suck

voraciously at the juices of plants, their jaws being well-developed. The females pass through no resting stage, but the males are quite passive before their last moult, closely approaching to the true pupa of the higher insects (fig. 76) (**124**).

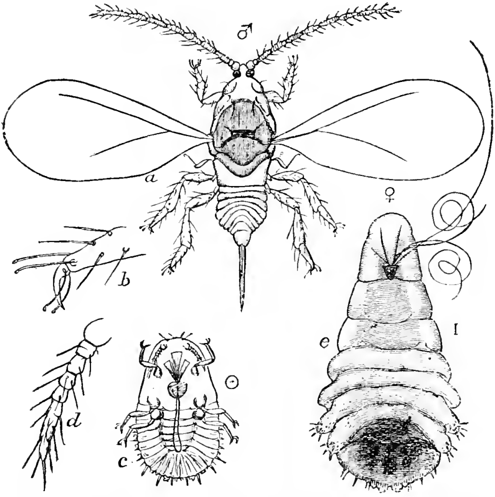


FIG. 110.—Scale Insect (*Mytilaspis pomorum*, Bouché.) Europe. *a.* male; *c.* nymph; *e.* female, magnified 20 times; *b.* foot; *d.* feeler, more highly magnified. From Howard, Yearbook, U.S.A. Dept. Agr., 1894. (See also fig. 170).

ORDER 8.—PLECTOPTERA.

Structure.—The MAYFLIES, which comprise this Order, are delicate insects of very remarkable structure. The head is relatively large, with a pair of short slender feelers of two or three segments; the jaws are vestigial, as Mayflies take no food in the perfect

state. The prothorax and metathorax are small, the mesothorax large. There are ten evident abdominal segments, the hindmost with a pair of very long, jointed cercopods, and often with a similar median appendage also. The legs are slender, the front pair being the longest. The forewings are much larger than the hindwings, which in some forms (*e.g.*—*Cloeon*) are quite absent; a large number of cross

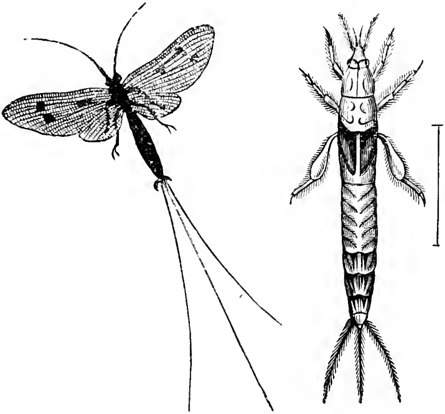


FIG. 111.—Mayfly (*Ephemera vulgata*, Linn.) Europe, natural size, and larva, magnified.

nervules between the longitudinal nervures causes a complex network on the wing surfaces (125). In one character of internal structure the Mayflies are the most primitive of all winged insects; the genital ducts are not only destitute of chitinous lining, as in Earwigs, but remain paired throughout life (49).

Development.—The eggs are dropped into water

wherein the larval and nymphal stages are passed. The grubs are very unlike their parents being typical campodeiform larvæ perfectly adapted for an aquatic life. In the younger stages, breathing takes place through the skin, but about the third moult (in Cloeon at least) paired abdominal gills and tracheal tubes are developed. The long tail-processes of the larvæ also serve as breathing organs, blood being driven backwards into them by a special hind chamber of the heart. The grubs feed on vegetable matter and small aquatic animals. After a long larval life, with many moults, the nymphal stage with rudimentary wings is reached, though the form of the nymph differs markedly from that of the imago. The winged form which emerges from the last nymphal instar is not the mature Mayfly but a "sub-imago"; this, by a final moult, gives rise to the true imago. Such a moult in the winged state is not known to occur in any other group of insects (**3**, **126**, **170**).

The Plectoptera include only a single family—the *Ephemeridæ* containing about 300 known species and distributed in all parts of the world (**125**).

ORDER 9.—ODONATA.

Structure.—The Dragonflies which make up this order are easily recognised by several well-marked characters. The head is large and very freely movable on the prothorax; the compound eyes are large and semi-globular, and there are three ocelli. The feelers are short, with two stout basal, and four or five slender segments, forming a bristle-like termination. The mandibles are powerful; the first maxilla has the hood and blade fused together, forming a spiny jaw-plate, and its palp has but one segment. The palps of the second maxillæ have very broad and flat sub-

terminal segments; and these form, together with the flattened blades of these maxillæ and the large hinged upper lip, a most efficient trap for catching the small insects on which dragonflies feed. The prothorax is small, the other two segments of the fore-body large; a side-view shows that they slope forward, the mesothorax lying to a great extent above the metathorax. By this arrangement the legs are thrust far to the front, the shins of all three pairs projecting beneath the head; they are fringed with many long spines and serve for catching prey during flight, or for clinging to plants; they are ill-adapted for walking. The wings, which are never absent, are very powerful, those of the two pairs closely alike, of firm glassy texture and incapable of folding; there are many longitudinal nervures, between which an immense number of cross nervules occur, marking out a multitude of quadrate cells over the wing area; a very characteristic feature in a dragonfly's wing is the node—a slight re-entrant angle on the costa whence arises a

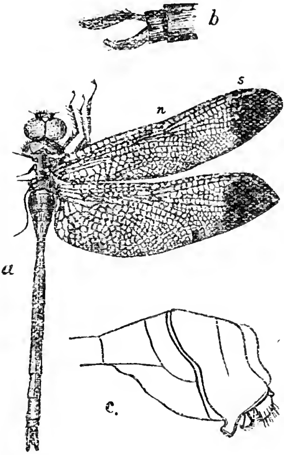


Fig. 112.—*a*. Dragonfly (*Zyxomma multinervis*, Carp.) Male, Papua; *n*. node; *s*. stigma, natural size; *b*. hinder abdominal segments from side, showing cercopods and ventral process; *c*. front abdominal segments from side, showing genital armature. Twice natural size. After Carpenter, Proc. R. Dubl. Soc., vol. 8.

strong cross-nervule. The hind-body is relatively longer than in any other insects; there are ten evident segments, the hindmost carrying a pair of stiff unjointed cercopods. The male genital armature is situated on the second abdominal segment—a position unknown in any other insects (fig. 112).

Habits and Development.—Dragonflies are insects of prey, pursuing and capturing smaller insects on the wing. Their flight is powerful, and some species migrate in swarms. They undergo a marked, though "incomplete" metamorphosis, the larval and nymphal stages being passed in water. The larvæ are somewhat sluggish creatures, with more conspicuous feelers, simpler legs (adapted for walking), and shorter and broader hind-bodies than are possessed by the perfect insects. The most remarkable feature in these larvæ is the modification of the second maxillæ to form an insect-catching trap—the "mask"; the sub-mentum is elongate and hinged with the head, the mentum also elongate and hinged to the sub-mentum, so that the whole organ can be folded and concealed beneath the head; a pair of strong, curved hooks with teeth are jointed to the mentum at its tip. When a small water-animal ventures too near the dragonfly-grub's head, the mask is suddenly shot out and these hooks seize the victim (3, 170).

Two well-marked families of Dragonflies may be distinguished.

Libellulidæ.—The *Libellulidæ* are dragonflies of comparatively robust build; the eyes touch each other in the centre of the head. The hindwings are broader at the base than the forewings, and there are at least five cross nervules between the root of each wing and the node. The larvæ and nymphs breathe chiefly by means of the rectum, whose walls are pierced by numerous looped air-tubes covered by membranous folds or papillæ; a set of plates surrounding the anus form a valve admitting water into the rectum at the insect's will. During late nymphal life they breathe also through thoracic spiracles, thrusting occasionally the head and fore-body out

of the water. This family is distributed in all parts of the world except the farthest northern regions (127).

Agrionidæ.—The *Agrionidæ* are dragonflies of more slender build, though some exotic genera (*Megaloprepus* and *Mecistogaster* for example) have longer abdomens and a wider wing-spread than any other insects. The head is relatively very wide, so that the two eyes are always far apart. The wings of the two pairs are exactly alike, and there are never more than two ante-nodal cross nervules. The larvæ are provided with three tracheal gills at the tail-end of the body, rarely also with paired gills on the abdominal segments; rectal gills are sometimes present in a rudimentary condition, and the older nymphs breathe, like those of the Libellulidæ, through thoracic spiracles. The family has as wide a range as the Libellulidæ (127).

ORDER 10.—NEUROPTERA.

In this order are included a number of families whose members agree in the possession of biting jaws and (with few exceptions) four nearly similar wings with complex net-veining. They differ markedly in their life-histories from those insects already described which resemble them superficially, as they all undergo a complete metamorphosis; the larva is usually eruciform. As characters drawn from the life-history are not available when adult insects only are before the student, it may be well to point out the cardinal structural distinctions between the order Neuroptera as here restricted and the preceding groups formerly included in it. The Plectoptera (Mayflies) and Odonata (Dragonflies) are both too distinct to be confused with any other insects; their reduced feelers distinguish them, at a glance, from the present Order. Among the Platyptera, the Perlaria have folding hind-wings which are unknown among the true Neuroptera, while the winged Corrodentia are distinguished by their simple neuration, and incompletely fused second maxillæ.

An adult insect then may be recognised as belonging to the present order, by the possession of conspicuous feelers and four membranous wings with

complex neuration, many cross nervules being present, except in the tiny *Coniopterygidæ* which have the hind-wings markedly smaller than the front pair, and are further distinguished by a white powdery covering. The only wingless genus among the Neuroptera is very scarce and is recognisable by the production of the head into a long snout.

The order may be divided into ten families (3, 129).

Sialidæ.—The *Sialidæ* or ALDER-FLIES have a quadrate head bearing a pair of long many-jointed, tapering feelers. The three thoracic segments are distinct and sub-equal, while the hindwings are slightly shorter than the forewings, though the neuration is closely alike in both pairs. The females lay their eggs in rows on rushes or grass-stems near water in which the larvæ live. The latter are carnivorous and very perfectly adapted for aquatic life, being provided with pairs of jointed gill-filaments on the first seven segments of the hind-body, and a long unjointed tail-process on the hindmost segment. The family includes only about five genera, with a discontinuous range in different parts of the world. The species of *Corydalis*, found in North and South America and Northern India, are remarkable for their gigantic size and the immense mandibles of the males (170).

Raphidiidæ.—The *Raphidiidæ* or SNAKE-FLIES are easily recognised by their narrow elongate prothorax and hind head-region, giving the appearance of a constricted neck. The female is provided with a long ovipositor. The larvæ are of the eruciform type, but without cercopods; they live in rotten wood and feed on small insects. The family contains only two genera, and is confined to the northern parts of the Old World and to North America.

Myrmeleonidæ.—The *Myrmeleonidæ* or ANTLION FLIES are, as a rule, large insects with prominent head, bearing a pair of short, clubbed feelers; the palp of the first maxilla has five segments, that of the second, three. The wings have the nervules at the tip so arranged as to form regular oblong cellules. The larvæ of these flies are the well-known "antlions," with powerful quadrate head and stout ovoid body. The mandibles are prominent and slender, grooved on their inner edge; through these grooves the juices of the insects whereon the antlion feeds is sucked into the gullet, the ordinary mouth-opening being closed. Some of these larvæ dig conical pits in which they entrap their prey; others hunt it, or lurk in concealed situations. The family is distributed throughout most of the tropical and temperate regions, ranging into southern Sweden, though unrepresented in these islands (fig. 113).

Ascalaphidæ.—The *Ascalaphidæ* are nearly related to the preceding family, which they resemble in their structure and life-

history. The feelers, however, are as long as the body, while the cellules at the tip of the wing are irregular in outline. The hindwings are broad at the base, like those of libellulid dragonflies, which the Ascalaphids resemble in appearance and habits; their long, clubbed feelers, of course, distinguish them at a glance from the Odonata. They do not range so far north as the Myrmeleonidæ, being confined in Europe to the Mediterranean region (129 *b.*).

Nemopteridæ.—The *Nemopteridæ* form a small but peculiar family, readily distinguished by their remarkable hindwings, which are much longer and narrower than the front pair, and more than twice as long as the body. The head is produced into a short beak; the feelers are long, slender, and not clubbed at the tip; the jaws both of the imago and the larva resemble those of the Myrmeleonidæ. The larva is of most striking appearance, possessing an elongate neck, like that of the snake-flies in an exaggerated degree. The distribution of the Nemopteridæ is remarkable; they are found in Southern Europe, Northern Africa, Western and Central Asia, and South America (Chili).

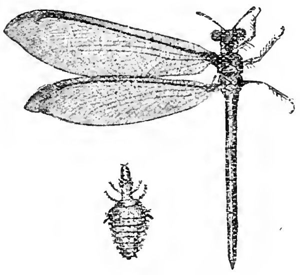


FIG. 113.—Antlion Fly (*Myrmeleon formicaleo*, Linn.), and its grub, South Europe. Natural size.

Mantispidæ.—The *Mantispidæ* are readily distinguished from all other Neuroptera by their elongate prothorax and raptorial forelegs, which give them an appearance like that of the Orthopterous family Mantidæ. From those insects, however, the Mantispidæ differ in the close similarity of their fore and hind wings, and in the total absence of cercopods to the hind-body. The eggs are stalked, and the active campodeiform larva is hatched in autumn; it spends the winter without feeding, and in the spring makes its way into the egg-cocoon of a hunting-spider or the nest of the wasp, where it devours the developing spiders or grubs, becoming changed into a fat, eruciform larva with stumpy legs (67). When full-grown it spins a cocoon and pupates within the dried larva skin, so that the mantispid on emergence has to break through its own puparium and cocoon, as well as through the spider's egg-bag or the wasp's nest. The Mantispidæ are a small family, but are distributed in all tropical countries, ranging north into southern Europe.

Hemerobiidæ.—The *Hemerobiidæ* or LACEWING-FLIES have four

similar wings with very complex neuration and numerous cells. The feelers are long, usually with bead-like segments, never clubbed. Simple eyes may be present (*Osmylinæ*) or absent (*Hemerobiinæ*). The larvæ are of the antlion form usual in this order. Those of Hemerobius are short grubs beset with hairy tubercles; they live on plants and feed on Aphids whose juices they suck, afterwards covering themselves with the dried skins of their victims. The larva of Osmylus is more elongate with exceedingly long mandibles, and lives partly under water. The family is generally distributed.

Chrysopidæ.—The *Chrysopidæ* or GOLDEN-EYE FLIES are nearly related to the Lacewings, but may be distinguished by the relatively longer feelers whose segments are cylindrical, not bead-like; the hind-body also is relatively longer. The eggs of these insects have long stalks by which they are attached to the stems and leaves of plants. The larvæ have the same habits as those of Hemerobius, hunting for aphids and sucking out their juices. This family also has a world-wide range.

Coniopterygidæ.—The *Coniopterygidæ* are tiny insects, covered with a white powdery secretion, and easily distinguished from all other Neuroptera by the paucity of cross nervules on the wings, and the very small size of the hind pair. The feelers are many-jointed, slender, and much longer than the body. The jaws resemble in structure those of the Hemerobiidæ and Myrmeleonidæ, and the larvæ also have similar form and habits; those which have been studied attack scale-insects and devour them by suction through their slender grooved mandibles.

Panorpidæ.—The *Panorpidæ* or SCORPION-FLIES differ so markedly from other Neuroptera that they are sometimes reckoned a distinct order (Panorpata or Mecaptera) (96, 97). The clypeus is excessively long and narrow, so that the head is produced into a prominent beak. The feelers are long, slender, and many-jointed. The mandibles are small and toothed, inserted at the tip of the beak. The first maxillæ have elongate stipites, extending down the beak on either side, and five-segmented palps; the palps of the second maxillæ have but two segments. The only wingless genus among the Neuroptera (*Boreus*) belongs to this family. The legs are long; in a foreign genus (*Bittacus*) excessively so, and adapted for seizing prey. There are nine evident abdominal segments; in *Panorpa* the last two or three can be recurved over the back, like the tail of a scorpion. The larvæ are like the caterpillars of moths or saw-flies, and are furnished (except in Boreus) with eight pairs of abdominal pro-legs in addition to the six thoracic legs, as well as with numerous spines, most of which disappear after the first moult. Both flies and larvæ are carnivorous. The family contains only nine or ten genera which are distributed over most parts of the world.

ORDER 11.—COLEOPTERA.

Structure.—The BEETLES make up a very natural and distinct order of insects, characterised by the horny or leathery texture of their forewings which serve as cases (elytra) for the folding membranous hindwings alone used in flight. (The recently proposed identification of the elytra of beetles with the tegulæ of Hymenoptera (15) rests on insufficient evidence.) The head is usually extended from behind forwards, having therefore a large crown and a small face; the feelers are very inconstant in form; the number of segments may vary from thirteen to one. The mandibles are always developed as strong biting jaws; the first maxillæ are of the typical form displaying the parts recognisable in the Orthoptera and lower orders; the second maxillæ are reduced and fused together basally in a very complete way to form the lower lip. In the fore-body the prothorax is free and movable; its tergite (pronotum) is a very prominent feature in all beetles, reaching back to the origin of the elytra. The scutellum of the mesothorax is sometimes visible as a triangular plate between the bases of the elytra. The parts of the ventral exoskeleton are well developed, sternum, and paired episterna and epimera being usually recognisable in all three segments. The legs vary greatly in form according to the insects' manner of life; the number of segments in the foot may be two, three, four or five. The hard forewings, when closed, usually cover the whole hind-body. They are strengthened with ridges around their edges, and marked with a series of longitudinal furrows (*striæ*) and often also with impressed dots (punctures). The hindwings are sometimes very small or wanting; in such cases the elytra are often fused together along their middle edges (suture). The hindwings when

developed exhibit a subcostal (mediastinal) nervure with which the radial (or scapular) nervures are largely confluent, several curved median and cubital nervures, and an anal; cross nervules and cells are few. The nervures are interrupted in their course to allow the transverse folding of the wing, which can be doubled up beneath the elytron. The hind-body may show as many as ten tergites, but the hindmost one or two are rarely evident; the first one or two abdominal sternites are usually reduced owing to the great extension of the metathorax and the haunches of the powerful hind-legs (**132, 134**).

Development.—As considerable space was devoted to the life-history of beetles in Chapter II; it is only necessary to repeat that they undergo complete metamorphosis, their larvæ exhibiting all stages of transition from the active campodeiform to the sluggish, legless eruciform grub, and that the pupa is free (**137**).

The Beetles are a numerous and universally distributed order though far less highly organised than the Moths, Flies, or Hymenoptera. Over 100,000 kinds have already been described. They are divided into a large number of families; the leading characters of the more important of these may now be defined (**132-136**).

Cicindelidæ.—The *Cicindelidæ* or TIGER-BEETLES are characterised by their large head, in which the face (clypeus) extends laterally in front of the eleven-segmented simple feelers, and the prominent eyes. The legs are long and adapted for fast running; all the feet have five segments. There are eight evident hind-body segments in the male, and seven in the female. The blade of the first maxilla ends in a hinged hook. The Tiger-beetles are very active in habit, pursuing the small insects on which they feed (fig. 114). They are represented in all parts of the world, though far more abundant in the tropics than elsewhere. Their larvæ have large heads, long legs, and imperfectly chitinised bodies without cercopods; they make burrows in sandy places and lurk in these on the watch for prey.

Carabidæ.—The *Carabidæ* or GROUND-BEETLES are a very large family nearly allied to the Cicindelidæ, but distinguished by the

narrower face, less prominent eyes, and the absence of a hinged hook to the tip of the first maxilla. There are eight or nine evident hind-body segments. The larvæ are active and campodeiform; in some genera the cercopods are long, in others much shorter; there are six ocelli on each side of the head. The Ground-beetles are mostly insect-hunters, but some species devour the roots of plants. The family is distributed in all parts of the world. (See fig. 157.)

Haliplidæ.—The *Haliplidæ* are a small family of beetles agreeing with those immediately following in their ovoid body-form and aquatic habit, but with the two preceding families in possessing a suture before the backward extension of the metasternum between the hind-haunches. The number of antennal segments is ten only. In this family the hind-haunches bear large plates which conceal much of the ventral surface of the abdomen. The larvæ are of elongate form, and each tergite is produced into four short granulose processes. The family contains only three genera, but one of these (*Haliplus*) is world-wide in range.

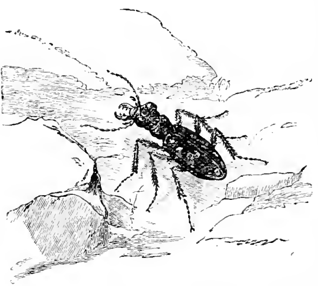


Fig. 114.—Tiger Beetle (*Cicindela campestris*, L.), Europe. Magnified.

Dyticidæ.—The *Dyticidæ* or Carnivorous Water-beetles are a large family distinguished structurally from the preceding families by the absence of a suture across the metasternum in front of the hind-haunches, which have no large plates, as in the Haliplidæ. The feelers, with eleven segments, are inserted close to the eye and the base of the mandible. The hind shins and feet are broad, flat, and furnished with numerous hairs. They are used as oars, and in conjunction with the evenly ovoid body adapt the insects very perfectly to life in the water. Eight abdominal segments are visible above. The larvæ are long and tapering in form with large heads armed with mandibles, which are grooved for suction of the juices of victims, after the manner of grubs of Neuroptera (see p. 203). The family is distributed in all parts of the world.

Gyrinidæ.—The *Gyrinidæ* or Whirligig-beetles are easily recognised by their very short feelers, the terminal segments of which are much condensed (fig. 6 *f*), and by the modification of the middle legs into oars as well as the hind pair. Each eye is divided into

two distinct areas. The extremely active whirling dance of these beetles in ponds and streams is well-known. Their larvæ are like those of the Dyticidæ, but the hind-body segments bear paired tracheal gills, whereas the grubs of the Dyticids breathe atmospheric air through the tail.

Hydrophilidæ.—The *Hydrophilidæ* are a family of beetles comprising both purely aquatic forms (*Hydrophilinæ*) (fig. 115) and marsh-living insects (*Sphaeridiinæ*). They are characterised by the great length of the palps of the first maxillæ; in the aquatic genera these are longer than the feelers, a character which at once separates the family from the Dyticidæ. The Hydrophilids are distributed in all parts of the world.

Staphylinidæ.—The *Staphylinidæ* or ROVE-BEETLES are an exceedingly large family principally characterised by their truncate elytra which are so short as to cover only a small part of the hindbody; the hindwings, when present, have a very simple neuration and can be completely folded beneath the elytra. The hind-body has ten segments, but the last two are usually retracted, so that eight only are evident; the segments are freely movable and always well chitinised, even those covered by the elytra. The feelers have as a rule eleven segments, but sometimes ten or nine. There are five tarsal segments. The Rove-beetles are usually narrow and elongate in form and very active in habit; they feed mostly on small insects, molluscs and worms, but some devour carrion, and others eat vegetable substances. The larvæ are active and campodeiform with well-developed legs and short two-segmented (rarely one-segmented) cercopods. About 7000 species of Rove-beetles have already been described, and the family is world-wide in its range.

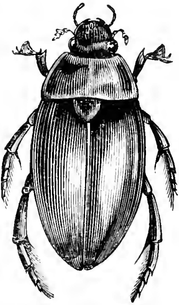


FIG. 115. — Water-Beetle (*Hydrophilus piceus*, L.). Natural size.

Pselaphidæ.—The *Pselaphidæ* are a family of very small beetles resembling the Staphylinidæ in their shortened elytra, but readily distinguished by their three-segmented feet, and their abbreviated hind-body in which only five segments can be recognised. The palps of the first maxillæ are very long, and the thighs are usually clubbed. The Pselaphidæ live among waste matter; they occur in all parts of the world.

Scydmænidæ.—The *Scydmænidæ* are a family of tiny beetles, which differ from the Pselaphidæ in their long elytra, almost or quite covering the hind-body, and their five-segmented feet. They are usually ovate in form, shining black or brown in colour; they

live in moss, under stones and bark, or in similar concealed situations. Like the Pselaphidæ they are sometimes found in ants' nests, and their range is world-wide.

Silphidæ.—The *Silphidæ* or CARRION-BEETLES are a large family including insects of very different sizes, characterised by straight clubbed feelers (usually eleven-segmented) which are inserted under the front margin of the head, quadrate mentum, margined pronotum, hind-body with only six evident segments, and large conical front haunches inserted close together. The shins are usually spined on the outer edge and the feet have five segments. The larvæ are active and campodeiform with small head, three-segmented feelers, broad thorax, and tapering hind-body with short or moderate cercopods. The larger members of this family (*Necrophorus*, etc.) are the well-known burying beetles which feed in carrion; the smaller genera (*Anisotoma* for example) live in moss, under bark of trees, etc. The family is distributed throughout the world, but seems better represented in temperate regions than in the tropics.

Histeridæ.—The *Histeridæ* are a family of small shining black or brown ovate beetles destitute of hair, but with the elytra distinctly striated. The feelers are short, the second segment being relatively very long, the terminal segments forming a flagellum with very distinct club; they can be retracted into grooves beneath the prothorax. The elytra are truncate behind, leaving the tip of the hind-body (which has five or six evident segments) exposed. The legs are short, with compressed shins and five-segmented feet. These beetles are mostly carrion-feeders, living in dung and carcases. The larvæ show an interesting transition stage between the campodeiform and eruciform types, having soft skin, and short legs and cercopods; they have no ocelli, but are provided with large mandibles; they feed on small insects. The family is world-wide in its range.

Trichopterygidæ.—The *Trichopterygidæ* are the most minute of all beetles; they may be recognised by their stalked, lance-shaped wings fringed on either side by long hairs. The feelers are long and slender, the three terminal segments forming a club, and bear hairs arranged in whorls. The feet have three segments only. The species are found in moss, dead leaves, and similar situations. The family is generally distributed.

Corylophidæ.—The *Corylophidæ* form another family of very tiny beetles with hair-fringed wings, which are, however, much shorter than in the Trichopterygidæ; the feet have four segments. This family is also of general distribution.

Coccinellidæ.—The *Coccinellidæ* or LADY-BIRDS are a very large family of beetles of rounded, convex form, usually shining and hairless. The short feelers have eleven segments, and end in a club. The head is retracted beneath the pronotum, which has a concave front edge. The hind-body, completely covered by the elytra, has five (rarely six or seven) segments evident beneath. The

cavities which receive the front haunches are closed behind. The legs are short, and largely hidden beneath the body; the feet are apparently three-segmented, the very small third segment being hidden in the lobes of the second. The claws are toothed (fig. 116). The larvæ are campodeiform, tapering before and backwards and possessing well-developed legs, but the skin is largely soft, protected by spine-bearing tubercles, and there are no cercopods. The lady-birds are often brightly coloured and marked with dark spots; both beetles and grubs are common on plants, where they devour aphids. The family is world-wide in its range.

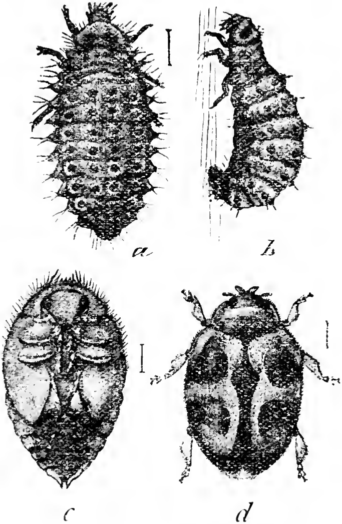


Fig. 116.—*d*. Ladybird Beetle (*Vedalia cardinalis*), Australia. *a*. *b*. larva; *c*. pupa. Magnified 7 times. From Riley, Insect Life, vol. 3 (U.S. Dept. Agr.).

Endomychidæ.—The *Endomychidæ* are nearly related to the Coccinellidæ but are usually more elongate in form and have longer feelers and legs. The pronotum has a transverse groove near its hinder edge, and a longitudinal impression on either side. The cavities of the front haunches are open behind, and the claws of the feet are simple. These beetles feed on plants, especially on fungi. They are found in most parts of the world, abundantly in tropical countries, less so in temperate regions. They are absent from New Zealand.

Erotylidæ.—The *Erotylidæ* are a family of beetles closely allied to the two preceding, but distinguishable from both (except in the case of a few Endomychidæ) by having the feet evidently four-segmented. The claws are simple as in the Endomychidæ, but the

cavities of the front haunches are closed behind as in the Coccinellidæ. Like the last family the Erotylidæ are pre-eminently fungus eaters. The larvæ are hairy with short legs and stout cercopods or anal spines. The species of this family are very numerous in the tropics, more sparingly represented in cooler regions.

Phalacridæ.—The *Phalacridæ* are a small family of beetles of small size, and ovate or sub-globular form, shining and hairless. The head is sunk beneath the pronotum, the eyes being half hidden and the feelers (eleven-segmented) arise below the edge of the face. The pronotum has margined sides and is as broad as the elytra, which entirely cover the hind-body. The legs are short and stout; the feet have five segments, and their claws are toothed at the base. The family is widely distributed.

Micropeplidæ.—The *Micropeplidæ* comprise only two genera of small beetles with short elytra, feelers concealed in cavities beneath the thorax, having the three terminal segments which form the club almost fused together, and very short three-segmented feet. They are found in vegetable refuse and marshy places, and seem almost confined to the Northern Hemisphere.

Nitidulidæ.—The *Nitidulidæ* are a large family of small beetles which show great diversity in their form, some being long and narrow, and others broadly ovate. The eleven-segmented feelers arise beneath the edge of the face; the three terminal segments form a club, and in some cases the last segment is sunk into the tenth. The feet usually have five segments, but in some genera the hind-feet of the males have only four. The Nitidulidæ live in all kinds of places—on flowers, in vegetable refuse, under bark, etc. Some of the members of the family found in the last-named situation prey on the grubs of wood-boring beetles. The family is universally distributed.

Trogositidæ.—The *Trogositidæ* are a small family of beetles which have, like the Nitidulidæ, five-segmented feet, but the first segment—not the fourth as in the preceding family—is very minute. They live mostly under bark and are distributed in most parts of the world.

Colydiidæ.—The *Colydiidæ* are a rather large family of small beetles, living like the preceding, mostly under bark, with which habit corresponds their elongate and cylindrical form. They may be distinguished from the allied families by their feet with four segments. The feelers are short and clubbed. The family is distributed in all parts of the world, but is most abundantly represented in the tropics.

Cucujidæ.—The *Cucujidæ* are a large family of beetles of oblong, flattened form; the eleven-segmented feelers, inserted on the edge of the face, are sometimes slender and sometimes end in a feeble club. The pronotum is often toothed at the sides. The feet have five segments whereof the first is small; occasionally the hind-foot has only four segments in the male. The Cucujidæ are abundant in the tropics, but poorly represented in cooler regions. Most of the

species live under bark, but some are found commonly in stored grain, like *Silvanus surinamensis* (fig. 117).

Lathridiidæ.—The *Lathridiidæ* are a large family of minute insects of oval form, the pronotum being usually narrower than the elytra. The mandibles are poorly developed; the palps of the first maxillæ have four segments, the last of which is large. The front haunches are conical and their cavities are closed behind. The feet are three-segmented, the third being long and having two simple claws. The larvæ are oval in form, soft-skinned, clothed with thickset hairs, without cercopods, but with a tail-appendage which serves as an additional foot. The beetles of this family live in vegetable refuse, fungi, etc. They are world-wide in their range.

Cryptophagidæ.—The *Cryptophagidæ* are another large family of

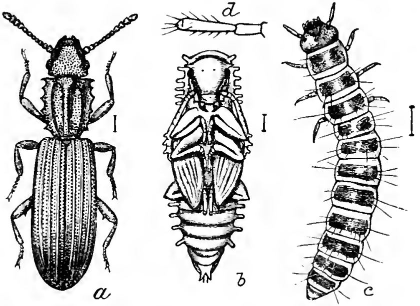


FIG. 117.—*a.* Grain Beetle, *Silvanus surinamensis* (Linn.), South America. *b.* pupa; *c.* larva, magnified 12 times; *d.* feeler of larva. From Chittenden, Bull. 4 (n.s.) Div. Ent. U.S. Dept. Agr.

minute beetles distinguished from the Lathridiidæ by their feet which have five segments (in the males of some genera the hind-feet have only four). From the Cucujidæ they may be separated by the distinctly clubbed feelers. They are oblong, oval, or almost circular in form; the sides of the pronotum are margined or toothed, and the upper surface is covered with short bristles or hairs. They are found under bark, in plant stems, or in vegetable refuse, and are distributed throughout the world, though most abundant in cool and temperate regions.

Mycetophagidæ.—The *Mycetophagidæ* are small oval or oblong beetles usually ornamented with red or orange spots, and covered with short hairs on the upper surface. The feet all have four

segments except the front pair in the males which have only three. The eleven-segmented, clubbed feelers arise in front of the eyes; the mandibles are bifid at the tip. The larvæ are campodeiform, the segments having chitinised tergites and long bristles, and the hindmost bearing a pair of short cercopods. The Mycetophagidæ live in fungi, under bark, and such obscure places. They are distributed over all parts of the world.

Dermestidæ.—The *Dermestidæ* are a family of beetles characterised by eleven-segmented feelers inserted in front of the eyes and ending in a club, a quadrate mentum, a short pronotum with cavities beneath for the reception of the feelers, a prominent mesosternum and a short metasternum, elytra not or very faintly striated covering the hind-body, short legs, the shins with stout spurs, and the feet with five segments of which the first four are short and equal and the fifth long with simple claws. The larvæ have small rounded heads with very short feelers, and six ocelli on each side; the body is thin-skinned with a dense hairy covering and the legs are short, each with a single claw. The pupa is partly clothed with the cast, hairy larval-skin. The Dermestidæ are distributed throughout the world; some live on plants, but the best known species—*Dermestes vulpinus* (fig. 118) for example—feed in skins and food-materials where they often do great damage.

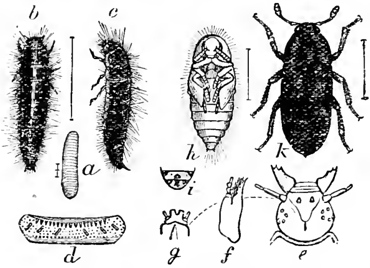


FIG. 118.—*k.* Skin-Beetle (*Dermestes vulpinus*), Europe. *a.* egg; *i.* tip of male abdomen from beneath; *b. c.* larva; *h.* pupa, 1¾ natural size; *d.* abdominal segment of larva with hairs removed to show spines and tubercles; *e.* head of larva; *f.* 1st maxilla; *g.* 2nd maxillæ of larva, more highly magnified. From Jones (after Riley), Insect Life, vol. 2 (U.S. Dept. Agr.).

Byrrhidæ.—The *Byrrhidæ* or PILL-BEETLES are oval, very convex beetles with head concealed beneath the pronotum. The clubbed feelers have eleven or (rarely) ten segments. The mesosternum is small and the metasternum short and broad. The legs are short and stout, largely hidden beneath the body; the shins have grooves into which the five-segmented feet can be folded back. The larvæ have the prothorax and the two hindmost abdominal segments chitinised, and much larger than the other segments which are soft-

skinned. The Byrrhidæ are found in moss, at the roots of plants, and some genera live in running water. They occur in all parts of the world.

Parnidæ.—The *Parnidæ* are a family of small beetles which have the feelers either long and thread-like, or very short with the second segment swollen. The head is usually withdrawn beneath the pronotum, and the prosternum stretches back beyond the haunches. The legs are long and slender; the feet have five segments of which the fifth is very long and the first four short. Tbe *Parnidæ* live in damp places, under running water, etc. They are found in all parts of the world.

Heteroceridæ.—The *Heteroceridæ* are a family of beetles with short eleven-segmented feelers, the first two segments being large and hairy, and the fifth to eleventh forming an oblong, saw-shaped club. The pronotum is broad with rounded corners. The legs are stout and adapted for digging; their feet have five segments, but the first is exceedingly minute. On either side of the first sternite of the hind-body is a curved, toothed ridge; the leg rubbed across this produces a shrill chirping note. The larvæ have a large head; the thoracic segments are twice as broad as the head, while the hind-body is very narrow; the body is covered with bristles and has stout, strong legs. The family includes but a single genus (*Heterocerus*) whose species live in damp places, on the banks of streams and ponds. They are almost confined to the northern temperate regions, a few only being known in the tropical parts of Asia and America.

Lucanidæ.—The *Lucanidæ* or STAG-BEETLES are a family of large beetles characterised by markedly elbowed feelers of ten segments, ending in a pectinate club, the pectinations being specially strong in the male (fig. 6 *d*). The mandibles are well-developed, in the male often of very large size. The cavities of the front haunches are closed behind; the mesosternum is short and the metasternum large. The elytra are rounded at the apex. The legs are long and the feet have five segments whereof the last is by far the longest. The larvæ are stout, white, fleshy grubs; the large, well-chitinised head has powerful mandibles and short feelers, but no ocelli; the body-segments are not transversely wrinkled. The grubs feed in the wood of trees and take several years to reach maturity. The family is numerously represented in the tropics, but becomes scarcer in cooler regions. Only three species are known in the British Isles.

Scarabæidæ. — The *Scarabæidæ* (CHAFERS, DUNG-BEETLES, etc.) are an exceedingly large family, including the most gigantic of beetles, though some of the species are of moderate or small size. They agree with the Lucanidæ in having the terminal segments of the feelers in the form of flattened plates, producing a comb-like club. In the Scarabæidæ these plates can be brought closely together so that the club appears compact (fig. 6 *h*), whereas the Lucanid feelers must always retain the pectinate form. The antennal plates

are relatively larger in the males than in the females. The pronotum, in this family, especially in the males, is often ornamented with conspicuous and curiously shaped horns whose purpose is unknown. In structural detail and habits the members of this family differ widely among themselves. Some are dung-feeders and certain foreign species roll together balls of dung wherein they lay their eggs, thus providing food for their grubs. Very many feed on plants, the beetles eating leaves, and the grubs roots. The grubs are white and fleshy, usually bent into a semicircle; the large head has powerful mandibles and no ocelli; the body-segments are often transversely wrinkled, and the hindmost segment is often

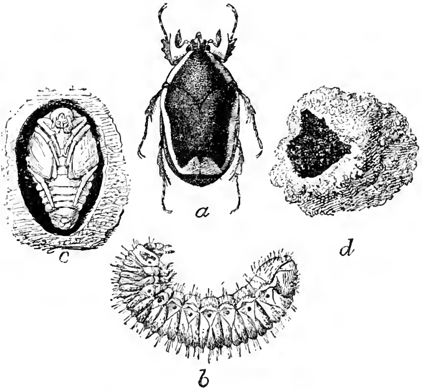


Fig. 119.—*a*. Chafer, *Allorhina nitida* (Linn.), North America. *b*. larva; *c*. pupa in cell; *d*. outside of cell. Natural size. From Howard, Bull. 10 (n.s.) Div. Ent. U.S. Dept. Agr.

greatly swollen. Some of the Scarabæidæ are dull black—the dung-beetles for example; while others are of bright metallic hues (fig. 119). The family ranges all over the world, but is most abundant in tropical countries.

Buprestidæ.—The *Buprestidæ* are a family of large or moderate-sized beetles. The somewhat short, eleven-segmented feelers are saw-like, owing to a distal enlargement of each segment. The head is withdrawn, as far as the large elliptical eyes, beneath the pronotum, whose hinder corners are not produced; the prosternum is drawn out behind into a spine which fits into a cavity in the meso-

sternum. The body is elongate and pointed behind. The short legs have the front trochanters large and free, and the feet five-segmented. The larvæ are remarkable on account of the small head, the very broad prothorax into which the head can be withdrawn, and vestigial legs; they feed under bark or in wood (fig. 120). The beetles are hard and firm in texture, and often of brilliant metallic colours; their elytra are used for ornamenting dresses in tropical countries, where the family is abundantly represented. In cooler regions the species are comparatively scarce.

Throscidæ.—The *Throscidæ* are a family of small beetles agreeing with the Buprestidæ in their elongate form and prosternal processes. The feelers are saw-like entirely or at the tip only. The prosternum is produced forwards as well as backwards; the hinder angles of the pronotum are also elongate, and the prothorax is closely jointed with the mesothorax. The front haunches are enclosed behind by the mesosternum. The family contains but few genera, and the species are, as a rule, dull and inconspicuous as well as small.

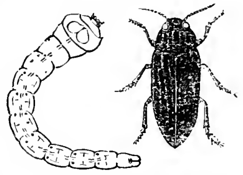


FIG. 120.—Beetle (*Chalcophora mariana*, Lap.), Europe, and its grub. Natural size.

Elateridæ.—The *Elateridæ* or CLICK-BEETLES are a large family, whose members agree with the Buprestidæ in their elongate form, prosternal processes, and short legs. The feelers, thread-like, saw-like or comb-like (fig. 6 *a*, *b*), arise in front of the eyes; the upper lip is free and visible. The hinder corners of the pronotum are drawn out and the prothorax is loosely jointed with the mesothorax, so that the sudden forcing of the prosternal process into the mesosternal cavity enables the beetles to leap high into the air when placed on their backs; the front coxal cavities are open behind and entirely prosternal, while the front trochanters are small. The larvæ of the Elateridæ are narrow elongate grubs with hard skins and short legs; they feed on roots, and those of various common species are well-known as "wire-worms" (fig. 121). The family is distributed in all parts of the world. The "fire-flies" of the tropics are large Elaterids which give out light from paired spots on the pronotum.

Eucnemidæ.—The *Eucnemidæ* are a family of beetles closely allied to the Elateridæ; some genera share with the members of that family the power of jumping when laid on the back. They are distinguished by having the upper lip hidden and the feelers inserted at the inner edge of the eyes. The larvæ resemble those of the Buprestidæ in having the prothorax very broad; the maxillæ as well as the legs are vestigial. The species are fairly numerous

in tropical countries, but become scarcer in temperate regions; only three are known as British.

Dascillidæ.—The *Dascillidæ* are a small family of beetles. The eleven-segmented, thread-like feelers are inserted directly in front of the eyes. The upper lip and the lobes of the second maxillæ are often distinct. The front haunches are inserted far apart and their cavities are open behind. The mesosternum is small, the metasternum moderate, and the hind-haunches almost in contact. The legs are rather short, the shins slender, and longer than the feet which have five segments. There are five visible sternites in the hind-body. The larvæ are short and broad, the prothorax being the largest segment; they are hairy and in one genus (*Helodes*) are remarkable for the great length of their feelers. The family is generally distributed.

Lampyridæ.—The *Lampyridæ* are a very large family of beetles

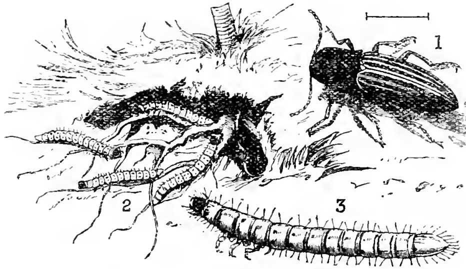


FIG. 121.—1. Click-Beetle, *Agriotes lineatus* (L.), Europe, magnified; 2. grubs or wireworms, natural size; 3. grub, magnified.

mostly of moderate size with the skin remarkably soft and flexible and clothed with short hairs; they are mostly elongate in form. The feelers are usually saw-shaped, but sometimes simple. The front haunches are conical and touch each other at their tips; their cavities are usually open behind. The feet have five segments. Six or seven sternites can usually be recognised in the hind-body. The larvæ are various in form; some bear short tail-processes, while in others the hindmost segment is provided with a sucker-foot. The family is widely distributed. Its best known members are the brightly coloured "soldier-beetles" (*Telephorus*) found on plants, and the "glow-worm"—the wingless larva-like female of *Lampyris noctiluca*, who attracts her flying, large-eyed mate by the light she emits.

Cleridæ.—The *Cleridæ* are a family of handsome, soft-skinned

beetles in which the body is elongate, the thorax being narrower than the elytra, and the head prominent. The eleven-segmented feelers are usually serrate, but sometimes end in a distinct club. The prosternum is short and the elytra completely cover the hind-body which has five or six evident sternites. The legs are long and the feet five-segmented, but in some genera the fourth is hardly recognisable, and in others the first is also very small. The larvæ are hairy, and bright red or brown in colour; the head has five ocelli on either side and two-segmented feelers; the thoracic segments have hard tergites, but the hind-body is fleshy, except the last segment which bears two points above and a short pro-leg below. The larvæ feed on small insects, and often devour the grubs of bees. The beetles live on trees or in carrion. The family is very abundant in the tropics, but scarcer in cooler regions.

Ptinidæ.—The *Ptinidæ* are a large family of small oblong or oval beetles with firm skin. The pronotum usually covers the head in great part, like a hood. The feelers are thread-like, saw-like, or comb-like. The convex elytra entirely cover the hind-body which has five visible sternites. The legs are long with thighs usually clubbed at the tip, and the feet have five segments. The larvæ are white fleshy grubs, bent in a half-circle like those of the Scarabaeidæ. The species of this family are generally distributed; they live in waste substances, decaying vegetable matter and old wood. *Anobium striatum* is often found in its larval and perfect stages in furniture, and the tapping of its stout mandibles gives rise to the familiar "death-tick."

Cissidæ.—The *Cissidæ* are a family of very small beetles with clubbed feelers of eight to ten segments, and the head and pronotum in the male armed with spines or projecting plates. There are five sternites visible in the hind-body, and the feet have only four evident segments. The beetles of the family are widely distributed, and live in fungi or rotting wood. The larvæ are white, fleshy grubs, but their tail-segment bears two long curved spines. The Cissidæ are found in all parts of the world.

Cerambycidæ.—The *Cerambycidæ* or Longhorn Beetles form one of the largest and best marked families of the Coleoptera. They are beetles of large or moderate size, and elongate form; frequently brightly coloured. The eyes are almost always concave on their forward edge; the feelers usually very long and thread-like, rarely saw-shaped or comb-shaped, and never clubbed. The mandibles are strong, and the palps of the second maxillæ have three segments. The prothorax is narrower than the elytra, usually cylindrical, sometimes toothed at the sides; the elytra nearly always cover the hind-body. The legs are sometimes stout and sometimes slender, the thighs often clubbed and the shins usually spined at the tip. The feet have five segments, but the fourth is very minute and fused with the fifth so that only four seem to be present; the third is broad and bilobed, and the first three are usually densely clothed

with short hairs beneath. The larvæ are fleshy grubs with very short legs; the head has short, four-segmented feelers, and strong mandibles; the prothorax is much larger than the following segments which become narrower as the tail-end is approached; all the segments bear chitinised sclerites and tubercles which act as sucker-feet. The grubs live and feed in the wood of trees (fig. 122). Consequently the Longhorns are most numerous in species in forest regions, and especially in the dense virgin forests of the tropics, though the family is distributed in all parts of the world where trees can grow.

Bruchidæ.—The *Bruchidæ* are rather small beetles, with the head, which is produced in front, partly hidden beneath the pronotum; the eleven-segmented feelers are saw-shaped or comb-shaped but never clubbed, though often broadened towards the tip. The elytra are rather short always leaving the hinder part of the abdomen exposed. The hind thighs are always thickened and the feet resemble those of the Cerambycidæ in form. The larvæ are short, stout, white, fleshy grubs with the legs absent or vestigial; they feed in seeds, chiefly of leguminous plants, the female beetle laying her egg on the seed-vessel of the flower and the young grub eating its way through, completing its development within the seed and there turning to a pupa (see fig. 70). The family is distributed in all parts of the world.

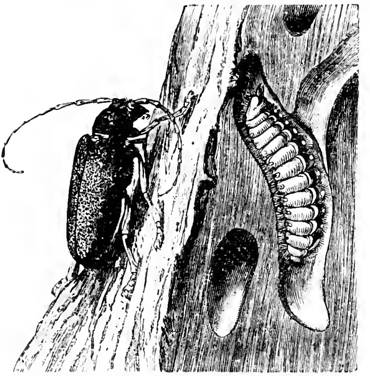


FIG. 122.—Longhorn-Beetle, *Saperda carcharias* (L.), Europe, and its larva. Natural size.

Chrysomelidæ.—The *Chrysomelidæ* or LEAF-BEETLES are an exceedingly large family closely allied to the *Cerambycidæ* which they resemble in most points of structure. In the Cerambycidæ, however, the epimera of the metathorax project backwards towards the first abdominal sternite, while in the present family the abdominal sternite is produced forwards at either side towards the metathorax. The relative shortness of the feelers serves to dis-

tinguish the present group, most of whose members are oval and convex in form, of moderate or small size, usually highly coloured and often metallic. Both the beetles and their grubs feed on leaves. The grubs are fleshy and stout, with distinct head and legs and swollen abdomen which often has an adhesive sucker-foot at the tail-end (see fig. 69). They often cause great damage to farm-crops. The family is distributed in all parts of the world.

Tenebrionidæ.—The *Tenebrionidæ* are a large family of beetles varying much in shape. The feelers, inserted beneath the sides of the head, with eleven segments, are thickened towards the tip, or slightly saw-shaped. The mandibles are stout with a basal tooth, and the first maxillæ have four-segmented palps. The elytra cover the hind-body which has five visible sternites. The legs are variable in form, but the front haunches are small and globular, and their cavities closed behind; the hind-feet have only four segments, while the front and middle feet have five. The larvæ are elongate, hard-skinned, cylindrical grubs with short legs and two prominences on the hindmost segment which serve as additional feet. The "mealworn" or grub of *Tenebrio molitor* is well-known for its ravages on stored flour. The beetles of this family (see fig. 85) live usually in fungi, rotting wood, and such hidden situations. One of the best known members is the true "black beetle"—*Blaps mucronata*—often found in cellars. The family ranges throughout the world.

Lagriidæ.—The *Lagriidæ* are a small family related to the Tenebrionidæ but differing in having the feelers threadlike, the front haunches conical and prominent, and the last segment but one of each foot bilobed with a dense hairy coating beneath. The legs are long and slender, and the number of foot-segments is as in the Tenebrionidæ. The beetles of this family have a short hairy (pilose) coating. The larvæ have comparatively long legs, and their segments often bear tufts of hairs. The family is generally distributed, but scarce in cooler regions; only one species occurs in the British Isles.

Cistelidæ.—The *Cistelidæ* are another small family related to the Tenebrionidæ; they differ from that family, as also from the Lagriidæ, in having the foot-claws toothed, while they agree with both the preceding families in their front coxal cavities being closed. The family is distributed in all parts of the world.

Melandryidæ.—The *Melandryidæ* are a large family, agreeing with the three preceding in the number of tarsal segments, but differing from them in having the front coxal cavities open behind. The head, which is not narrowed behind, is hidden by the thorax as far forward as the eyes. The pronotum is as broad, or nearly as broad, as the elytra, which cover the hind-body with its five visible sternites. The legs are usually long and slender, the front haunches globular. The larvæ are elongate and cylindrical, with chitinised head, thorax, and tail-segment, the rest of the body

being soft-skinned. The family is generally distributed, but the species are more plentiful in temperate regions than in the tropics.

Pythidæ.—The *Pythidæ* are a small family, agreeing with the Melandryidæ in most structural features, but distinguished by the heart-shaped or oval pronotum, which is narrower than the elytra at its hinder edge. These beetles live under bark and in dead wood; they are widely distributed over the northern continents, but are scarce in the tropics.

Œdemeridæ.—The *Œdemeridæ* are a rather large family agreeing with the Melandryidæ in most points, but distinguished by the long conical front haunches. The feelers are long and threadlike. The last segment but one of each foot is bilobed, and the thighs of the males are often very thick. The beetles are often brightly coloured and occur on flowers; they are widely distributed, but seem commoner in temperate regions than in the tropics. The larvæ are long and narrow with the head usually rather broad.

Pyrochroidæ.—The *Pyrochroidæ* are a small family of beetles usually bright red in colour, and characterised by the head, which is carried projecting in a horizontal position, being very strongly narrowed behind the eyes, and the eleven-segmented feelers being markedly serrate or pectinate (fig. 6 *e*). The thorax is narrower than the elytra. The front haunches are long and conical, their cavities broadly open behind. The legs are long; the number of tarsal segments as in the six preceding families, the last segment but one being bilobed and the claws simple. The larvæ are long and narrow with broad head and stout legs; only the thorax and last abdominal segment (which bears two strong spines) are hard-skinned. The few species of this family are almost confined to the northern continents.

Mordellidæ.—The *Mordellidæ* are distinguished from the Pyrochroidæ by their small, globular, front haunches, and thread-like or only slightly saw-like feelers; while the head, markedly narrowed behind the eyes, separate them from the Melandryidæ and Pythidæ, and the open coxal cavities from the Tenebrionidæ and Lagriidæ. They are convex insects with slender legs, the hind-feet being especially long, often twice as long as the shins. The family is generally distributed, but the species are most numerous in the northern continents.

Rhipidophoridæ.—The *Rhipidophoridæ* are nearly related to the Mordellidæ but are distinguished by their prominent, conical front haunches. From the Pyrochroidæ they are separated by the relatively wider prothorax; this is not narrower than the elytra, which are short and divergent at their tips, not covering the wings. The feelers are comb-shaped in the males and saw-shaped in the females. The legs are long and the foot-claws bifid at the tip. The family is widely distributed, but appears to be absent from the Australian Region. A single species only (*Metoecus paradoxus*) occurs in Great Britain. Its larva, which lives parasitically in

wasps' nests is at first a minute, armoured campodeiform grub, and afterwards a white, legless maggot.

Anthicidæ.—The *Anthicidæ* are a large family of very small beetles, which agree with the Rhipidophoridæ and Pyrochroidæ in most structural points, being distinguished from the former by their narrow prothorax, and from the latter by the drooping head and thread-like feelers. The species, some of which are like ants in appearance, live in sandy places or in salt-marshes; the family ranges throughout the world.

Meloidæ.—The *Meloidæ* are large or moderate-sized insects with the head constricted behind the eyes, the prothorax at its hinder edge narrower than the elytra, the legs long with front haunches large and conical, the feet with the last segment but one not bilobed, and the claws split to the base. The larvæ of several genera undergo a hypermetamorphosis, being at first active and campodeiform, and then becoming legless, parasitic maggots. The Oil-beetles (*Meloe*) are well-known, dark, elongate insects with very short elytra and long, large abdomen; their larvæ are parasitic in bees' nests. The "Spanish Fly" (*Lytta vesicatoria*) a bright green beetle, and several species of the exotic genus *Mylabris*—mostly brightly-spotted insects—are used medicinally for blistering purposes.

The four next families are distinguished by the marked elongation of the head into a beak or snout—they form the group Rhynchophora and are easily recognised from almost all other beetles. The feet consist of four evident segments whereof the last but one is bilobed.

Anthribidæ.—The *Anthribidæ* are a large family characterised by a distant labrum and by the palps of the first maxillæ being jointed and flexible as in beetles generally. The straight feelers end in a three-segmented club; in some genera—especially in the males—they are of enormous length. The snout is usually relatively short. The family is generally distributed, but is much more abundant in the tropics than in cooler regions.

Brenthidæ.—The *Brenthidæ* are characterised by their narrow and elongate shapes, very greatly produced snout, and short clubbed feelers. They are beetles of most striking appearance, and mostly coloured black and red or yellow. The family is almost confined to the tropics; only two species reach northwards to southern Europe.

Curculionidæ.—The *Curculionidæ* or WEEVILS are an exceedingly large family characterised by the absence of a distinct labrum and by the short, rigid and conical palps of the first maxillæ. The snout is always distinct, sometimes very long, and the feelers are often divided into a scape and flagellum. In size, colour, and details of shape the numerous genera show very great variation.

The larvæ are white, fleshy grubs, usually without legs, with greatly wrinkled skin, and bent bodies (fig. 123). Both they and the beetles are vegetable-feeders; many species cause great damage by their attacks on the roots, leaves, and wood of cultivated plants. The family is world-wide in its range.

Scolytidæ.—The *Scolytidæ* or BARK-BEETLES are small cylindrical beetles which agree with the Curculionidæ in the short, rigid palps of the first maxillæ, and in the absence of a distinct labrum, but differ markedly in the slight development of the snout. The strongly clubbed feelers are inserted on the sides of the head between the eyes and the mandibles. The pronotum often covers the head; the legs are stout with the foreshins toothed on the outer edge (fig. 124). The larvæ are legless grubs like those of the Curculionidæ; they and the beetles usually live in galleries which they eat out in trees between the bark and the wood; a primary tunnel is made by a female who lays eggs therein, and the grubs when hatched quickly make branch-galleries (see fig. 163).

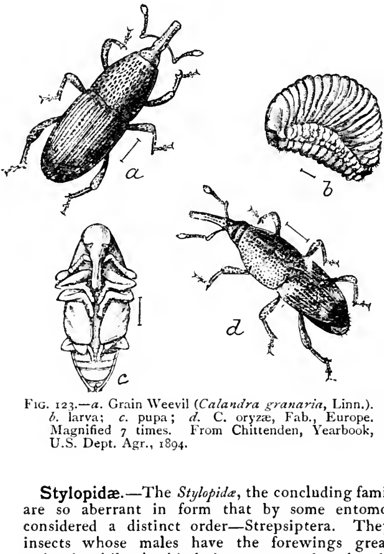


FIG. 123.—*a*. Grain Weevil (*Calandra granaria*, Linn.). *b*. larva; *c*. pupa; *d*. C. oryzæ, Fab., Europe. Magnified 7 times. From Chittenden, Yearbook, U.S. Dept. Agr., 1894.

Stylopidæ.—The *Stylopidæ*, the concluding family of the Beetles, are so aberrant in form that by some entomologists they are considered a distinct order—Strepsiptera. They are very small insects whose males have the forewings greatly reduced and twisted, while the hindwings are very broad and fold lengthwise. The feelers are branched, and the jaws much reduced. The females are blind and worm-like; they spend their whole lives within the bodies of bees and other insects whereon they are parasitic, and in

this position they are fertilised by the free-flying male. The tiny campodeiform larvæ are hatched within the mother's body. Escaping to the outer surface of the bee-host they are carried to her nest, where they bore into a bee-grub and become changed into legless maggots. The presence of the parasite does not hinder the development of the bee-larva, but when the latter has undergone the final change it flies carrying the Stylopid—if a female—within its abdomen. The Stylopidæ are probably widely distributed, but little is known of them outside Europe and North America

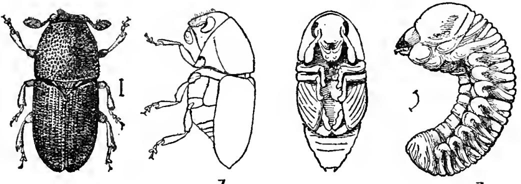


FIG. 124.—Bark-Beetle (*Scolytus rugulosus*, Ratz.), Europe. *a*. Beetle from above; *b*. side view; *c*. pupa; *d*. larva. Magnified 10 times. From Chittenden, Circular 29 (2nd ser.), Div. Ent. U.S. Dept. Agr.

ORDER 12.—TRICHOPTERA.

Structure.—This order comprises the CADDIS-FLIES, which were formerly united with the Neuroptera. Their structure is, however, very distinct. The wing-surface, as well as the insect's body, is covered with hairs. The fore-wings are long and narrow, the hind-wings usually broad and somewhat shorter, with folding anal area; the neuration is predominantly longitudinal, the principal nervures forking repeatedly and being connected by few cross nervules. A fold of membrane (*jugum*) at the base of each wing is a characteristic feature. Mandibles are absent, and the two pairs of maxillæ are united to form, with the upper lip, an imperfect sucking apparatus (139); the feelers are long, slender, and many-jointed. The palps of the first maxillæ have five segments in the females,

and a variable number in the males. The mesothorax is the largest segment of the fore-body. The legs have large haunches which are inserted close together; this character readily separates Caddis-flies from Stone-flies to which they bear a distant superficial likeness. There are nine evident segments in the abdomen, the hindmost, in the male, bearing a pair of claspers (3).

Habits and Development.—Caddis-flies are feebly-flying insects, often nocturnal in their habits and frequenting the neighbourhood of the waters wherein their preparatory stages are passed. The female drops her eggs, which are enclosed in a jelly-like substance, into a pond or river. The larvæ are intermediate between the campodeiform and eruciform type; the thoracic segments—each bearing a pair of legs—are partly chitinised like the head; while the ten-segmented hind-body is soft and bears thread-like tracheal gills. The tail-segment is provided with a pair of hooks whereby the larva clings to the inside of the protective case which it builds by cementing various foreign objects—sticks, stones, shells, etc.—with the secretion of its spinning-glands. Most of the larvæ or "caddis-worms" feed on water-plants, but some devour other insects, etc. When full-grown the larva closes up both ends of its case and changes into a free pupa, closely like the imago, except for the presence of strong mandibles. By means of these the pupa is able to bite its way out of the case and rise to the surface of the water; after emerging into the air the final moult is undergone (3, 170).

Caddis-flies are distributed in all parts of the world. They have been divided into seven families, which are discriminated by somewhat small structural characters (138).

Phryganeidæ.—The *Phryganeidæ* are large caddis-flies in which the palps of the first maxillæ in the male are hairy and four-segmented; the feelers and legs are stout. The larvæ inhabit sluggish and standing waters, and make cases composed of vegetable fibres or pieces of leaf.

Limnephilidæ.—The *Limnephilidæ* are mostly large insects, but of less robust build than the Phryganeidæ. The first maxillary palp of the male is three-segmented. The larvæ vary in their habits and in the form of their cases.

Sericostomatidæ.—The *Sericostomatidæ* have males with two or three-segmented palps; they may be distinguished from the Limnephilidæ by the absence of ocelli. The larvæ live in running streams and build cases of grains of sand and small stones.

In the four succeeding families the males have, like the females, five segments to the palps.

Leptoceridæ.—The *Leptoceridæ* have long feelers and very hairy palps whose terminal segment is flexible but simple. The larvæ make cases of fine sand; these are sometimes straight and sometimes curved.

Hydropsychidæ.—The *Hydropsychidæ* have the palps rather hairy, the last segment being very long and jointed. The larvæ live in running water, and make fixed abodes of small stones; they feed on smaller insects, some species spinning a silken net which serves to capture prey.

Rhyacophilidæ.—The *Rhyacophilidæ* have the palps almost without hairs, and their terminal segment simple and cylindrical. The larvæ live in swift streams and make a fixed heap of small angular stones beneath a large stone; they retreat therein when in danger or about to pupate.

Hydroptilidæ.—The *Hydroptilidæ* are small and hairy insects resembling clothes-moths in appearance; the wings are narrow, the hindwings being narrower than the front pair. The larvæ, which are without gill-filaments, make portable cases.

ORDER 13.—LEPIDOPTERA.

Structure.—MOTHS and BUTTERFLIES are readily distinguished from all other insects by the multitudinous flattened scales which cover their wing-surfaces, giving rise to characteristic coloured patterns. The head bears large, semi-globular, compound eyes, and long, many-jointed feelers. Except in the lowest family the mandibles are reduced to tiny vestiges, and the galeæ of the first maxillæ are

elongate and grooved on their inner surfaces, so as to form, when in apposition, a sucking-tube. The palps of the first maxillæ are sometimes present; those of the second, nearly always. The segments of the fore-body are firmly united together, the pronotum is small and bears a pair of erectile plates, the *patagia;* the meso- and meta-scuta form the greater part of the

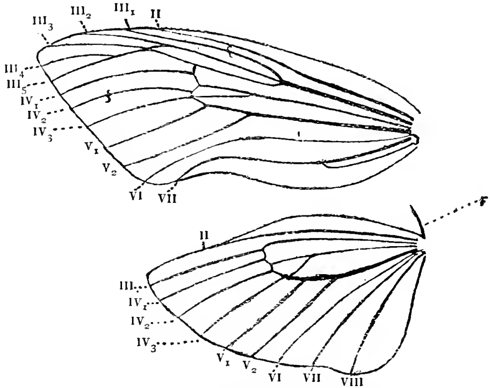


Fig. 125.—Wing-neuration in a Cossid Moth. II. Sub-costal; III. radial; IV. median; V. cubital; VI. VII. VIII. anal nervures. From Quail, Natural Science, vol. 13.

thoracic skeleton dorsally. A pair of small scales—the *tegulæ*—overlapping the bases of the forewings are borne on the mesothorax. The forewings are larger than the hindwings, but the latter have in most cases a better developed anal area than the former. The neuration is predominantly longitudinal. In a typical lepidopterous wing there are (fig. 125, II) a simple, unbranched sub-costal nervure; (III) a five-branched radial nervure; (IV) a three-branched median

nervure; (V) a two-branched cubital nervure; (VI, VII, VIII) three simple anal nervures.[1] But few cross nervules are present; these are usually arranged so as to form, in conjunction with the branches of the radial, median, and cubital nervures, a large polygonal discoidal cell. In the lowest families of Lepidoptera the hindwings are closely like the forewings in shape and neuration, but in most cases the latter are larger and more pointed; the number of anal nervures in the forewings, and of radial branches in the hindwings, tends to be reduced. In the lowest families a membranous fold (jugum) is present at the base of each forewing, as in Trichoptera. In most other Lepidoptera, union of the two wings of a side is effected by a bristle—the frenulum (fig. 125 *F*) arising from the base of the hindwing and fitting beneath a number of stiff hairs on the lower surface of the forewing. In a fair number of female moths the wings are greatly reduced or quite absent. The legs, provided with spines and covered with hairs and scales, have small haunches, long shins, and five-segmented feet; in some cases the feet are greatly reduced. The hind-body in the Lepidoptera has seven segments only visible, but nine are apparent on dissection, hinged lateral processes on the ninth serving as genital claspers in the male (**2, 145**).

Habits and Life History.—The insects of this order feed almost entirely on honey which they suck from flowers, but a fair number take no food in the perfect state, there being a complete division of labour between the larval and imaginal stages. The families of Lepidoptera popularly distinguished as

[1] The American system of nomenclature is adopted here as corresponding best with the other Orders. In most British works the five systems of nervures in the Lepidoptera are called respectively: costal; sub-costal; radial; median; and internal.

"Butterflies," and a large number of Moths are on the wing in the daytime; many Moths fly only in the evening or at night. The larvæ of Lepidoptera are elongate caterpillars usually with five pairs of abdominal prolegs in addition to the six thoracic legs. They are provided with powerful mandibles and eat the leaves or the wood of plants. The body-segments are studded with bristle-bearing tubercles (fig. 126 *b*)

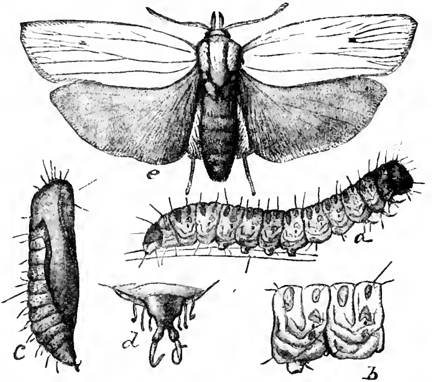


FIG. 126.—*e*. (*Crytophasa unipunctata*, Donov.), Australia; *a*. larva; *c*. pupa, natural size; *b*. 2nd and 3rd abdominal segments of larva; *d*. cremaster of pupa, magnified. From Edwards, Insect Life, vol. 3 (U.S. Dept. Agr.).

which have a characteristic arrangement in the different families (144). The pupa, usually enclosed in a cocoon of silk, or of foreign materials worked up with silk, is free in the two lowest families, becoming more and more obtect in the higher. A variable number of abdominal segments are movable; in the lower families rows of spines on the dorsal surface

of the hind-body enable the pupa to emerge partially from its cocoon. The abdomen often ends in a strong flattened spine, the cremaster (fig. 126 *d*) frequently beset with numerous curved hooklets which anchor to the silk of the cocoon when the pupa has got far enough out, or serve to suspend those pupæ not enclosed in cocoons from their pad of silk.

Classification.—The popular division of Lepidoptera into "Butterflies" (*Rhopalocera*) and "Moths" (*Heterocera*) is quite unscientific, the butterflies being more nearly related to the higher moths than these to the lower moths. It has been proposed (5) to separate the three lowest families which have, like. Trichoptera, a jugum on each forewing—as *Jugatæ* from all other Lepidoptera—*Frenatæ;* also (77) to divide the families with incomplete pupæ (*Incompletæ*) from those with obtect pupæ (*Obtectæ*); also (145) to separate the lowest family on account of the structure of the first maxillæ as a sub-order (*Laciniata*) distinct from all the other families (*Haustellata*). On the whole it is better not to adopt any division of the Lepidoptera between the order and the family (146).

Micropterygidæ.[1]—The *Micropterygidæ* form the lowest family of moths, with striking affinities to the Caddis-flies. They are very small insects with bronzy-golden wings, differing from all other Lepidoptera in the first maxillæ having laciniæ as well as galeæ, the latter parts not being elongate or grooved. The mandibles though small are quite recognisable; in the pupa these jaws are large and functional, serving to bite a way out of the cocoon. The forewing has a jugum and its sub-costal nervure is forked; except for this character the neuration of the hindwing is closely similar; the number of cross-nervules is greater than in the higher families. The caterpillars have eight pairs of prolegs (an exceptionally large number among Lepidoptera) and feed in damp moss (77, 145). The family is, so far as known, found only in Europe and North Africa, America, and New Zealand; it contains very few genera and species.

Eriocraniidæ.[2]—The *Eriocraniidæ* agree with the preceding family

[1] *Eriocephalidæ* of Packard. [2] *Micropterygidæ* of Packard.

in the form and neuration of their wings—except that the sub-costal nervure is simple and that there are fewer cross-nervules—as well as in the possession of functional mandibles by the pupa. But in the imago the mandibles have vanished and the galeæ of the first maxillæ form a sucking-tube as in Lepidoptera generally, though the organ is short in this family. The Eriocraniidæ are small moths closely like those of the preceding family in appearance. The footless larvæ mine the leaves of trees and the pupal stage is passed underground. As in the preceding family the pupa is "free." The family, containing but a single genus and a dozen species, is confined to Northern and Central Europe.

Hepialidæ.—The *Hepialidæ* or SWIFT MOTHS resemble the two preceding families in wing structure, a jugum being present and the neuration in fore and hind wings being closely similar. But they agree with the following families in the absence of mandibles in the pupa as well as in the imago. The palps of the first maxillæ, well-developed in the two preceding families, are wanting in the Hepialidæ; these jaws as a whole indeed are vestigial, no food being taken in the perfect state. The Swift Moths are large or moderate-sized insects usually brown or yellow in colour of the wings which are sometimes adorned with metallic spots. Their larvæ—of the usual lepidopterous type with ten pro-legs—live underground and feed on roots; the "incomplete" pupæ also are subterranean. The family does not comprise many genera, but is world-wide in its range; the only British genus is *Hepialus*.

Zygænidæ.—The *Zygænidæ* or BURNET MOTHS are small day-flying insects adorned with bright metallic colours—in the two British genera (*Zygæna* and *Ino*) scarlet and black, or green. The forewings, with three anal nervules, whereof two are confluent, are narrow, and longer than the hindwings, in which three distinct anal nervures are present, and the sub-costal nervure is joined to the radial by a short cross-nervule; vestiges of the median trunk nervure can often be traced in all the wings traversing the discoidal cell. There is, as in all the succeeding families, no jugum, but a frenulum is present. The feelers are rather long, stout, and tapering with short processes or pectinations. The sucking-tube is developed, but the first maxillary palps are vestigial. In the structure of the imago the Burnets are less primitive than some other families, but the pupa has as many as five movable segments in the abdomen. It is protected by an elongate cocoon spun on the food-plant. The larvæ, with the usual five pairs of prolegs, are stout and cylindrical, feeding openly on various plants, and often conspicuously marked with black and yellow. The family is very widely distributed, and rich in genera and species.

Chalcosiidæ.—The *Chalcosiidæ* are a family of tropical day-flying moths of brilliant coloration, allied to the Zygænidæ with which they agree closely in structure. The wings, however, are less narrow in form and the feelers have longer pectinations which

give them a distinctly swollen appearance. The larvæ are covered with numerous tubercles and hairs.

Limacodidæ.—The *Limacodidæ* are a family of moths nearly related to the Zygænidæ, which they resemble in the number of anal nervures in both fore- and hind-wings; the sub-costal nervure of the hindwing, however, bends downwards and anastomoses with the radial, afterwards separating, instead of being joined to it by a cross-nervule. The forewings, moreover, are relatively broader than in the Burnets, while the first maxillæ are greatly reduced, no food being taken in the perfect state. The Limacodidæ fly at night, and are usually yellow or brown in their wing-patterns. The caterpillars are broad and slug-like with very small, retractile limbs; they feed openly on the leaves of plants, and some exotic forms are armed with stinging tubercles. The pupal segments are as in the Zygænidæ, but the pupa is enclosed in a hard cocoon, a circular lid allowing the moth to emerge. The Limacodidæ are fairly numerous in the tropics but scarce elsewhere; only two species are British.

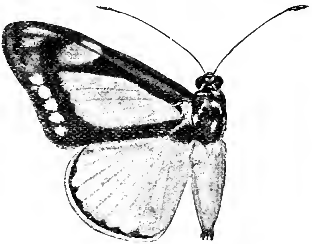


FIG. 127. — *Castnia cronis*, Cram., Male, Mexico. Natural size. From Edwards, Insect Life, vol. 3 (U.S. Dept. Agr.).

Castniidæ.—The *Castniidæ* are a small family of large, day-flying, brightly-coloured moths whose wing-neuration closely agrees with that of the Zygænidæ. The feelers are clubbed, as in the higher families of Lepidoptera ("butterflies") but the Castniids may be readily distinguished from them by possessing a frenulum, as well as by the much more primitive neuration (fig. 127). The larvæ are devoid of spines, and feed in the stems or roots of plants; there are three or four free pupal segments. The family is confined to Tropical America, Indo-Malaya, and the Australian Region.

Megalopygidæ.—The *Megalopygidæ* are a small family of hairy American moths with broad rounded wings whose neuration resembles that of the Burnets, except that the three anal nervures of the forewing are distinct for the greater part of their length. The larvæ are very remarkable in having seven pairs of prolegs, the only instance among Lepidoptera except the Eriocephalidæ of there being more than five pairs present.

Psychidæ.—The *Psychidæ* are a small but universally distributed family of moths characterised by the extreme degradation of their females. The larvæ live in portable cases made of sticks, grass,

leaf-fragments, etc., with a silk lining; the pupæ, which have three or four free segments, find protection in these cases, and the worm-like females without feelers, jaws, legs, or wings, also live and die in them. The free-flying males have strongly-toothed comb-like feelers, but no functional jaws. The wing-neuration is of the Zygænid type, but there is a complex anastomosis between the three anal nervures of the forewing. The wings are usually grey or dusky in colouration.

Heterogynidæ.—The *Heterogynidæ* are a family containing a single south European genus. These insects resemble the Psychidæ in appearance and habits, but the larvæ do not form cases. The female emerges from the cocoon to pair, but remains attached to the ventral face of the pupa-skin, and withdraws again into the cocoon for the purpose of laying her eggs.

Cossidæ.—The *Cossidæ* are a small but universally distributed family of rather large moths with all parts of the jaws very small or vestigial, no food being taken in the perfect stage. The wing-neuration is of the Zygænid type, but the forking of the main median nervure in the discoidal cells of all the wings is characteristic (fig. 125). The larvæ with the usual five pairs of prolegs feed within the stems of plants, often in the wood of trees. The pupæ with three to five free segments are protected in cocoons made up of chips of the food plant, exceptionally in earthern cocoons. The species are most numerous in the tropics; in our islands three only occur, of which the "Leopard" moth *Zeuzera pyrina* (fig. 128) and the "Goat" (*Cossus cossus*) are well known.

Sesiidæ.—The *Sesiidæ* or CLEARWINGS are a large family of somewhat small day-flying moths with narrow wings which are for the most part without scales. They have clubbed feelers, well-developed first maxillæ without palps, and a frenulum. In wing-neuration they differ from all the preceding families; three anal nervures are present in the hindwing, but one and a trace of a second only in the forewing. The second of the three median nervures in the forewing is midway between the other two, the nervures generally coming off from the cell at equal distances from each other; there is no sub-costal nervure in the hindwing. Many of the Clearwings are much like Hymenoptera in appearance. Their caterpillars, with five pairs of prolegs, feed within the wood of plants. The pupa with three or four free segments remains within its cocoon of chips until the time of emergence comes, when it makes its way partly out of the food-tree by means of the spines on its hind-body segments.

Tortricidæ.—The *Tortricidæ* are a very large family of small moths, agreeing in most structural points with the Sesiidæ. In veriiindwing the sub-costal nervure is, however, always present and second anal nervure is forked at the base. The feelers are not swollen; the first maxillæ are usually well-developed though their palps are wanting; the palps of the second maxillæ end bluntly. The larvæ, with five pairs of prolegs, feed within the tissues of plants, or in

leaves rolled up or fastened together by silken threads. The pupal structure is like that of the Sesiids (fig. 126). The markings of the forewings usually show one or more bands and sometimes metallic spots.

Tineidæ.—The *Tineidæ* are an immense family of small moths

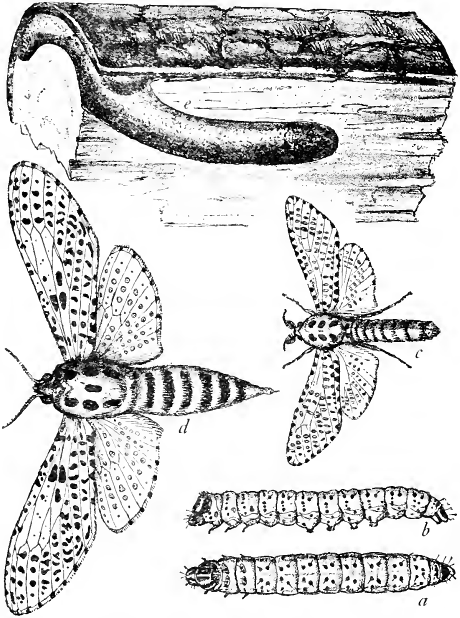


Fig. 128.—"Leopard" Moth (*Zeuzera pyrina*, L.). *a. b.* caterpillar; *c.* male; *d.* female; *e.* burrow of larva in wood. Natural size. From Pike, Insect Life, vol. 4 (U.S. Dept. Agr.).

showing great variation in structure. The wing-neuration is normally like that of the Tortricidæ, but the middle anal nervure of the hindwing is not forked at the base. The wings are usually very

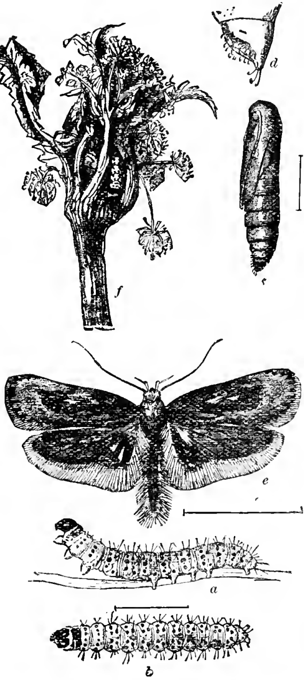


FIG. 129.—*e.* Carrot Moth (*Depressaria heracliana*, D.G.); *a. b.* caterpillar; *c.* pupa, magnified $2\frac{1}{2}$ times; *d.* tail-end of pupa, more highly magnified; *f.* shoot of parsnip, with web spun by caterpillars, natural size. From Riley, Insect Life, vol. 1 (U.S. Dept. Agr.).

narrow and often pointed, and a degradation of the neuration sometimes results, many of the nervures disappearing. The feelers are thread-like, the palps of the first maxillæ are often developed and the palps of the second maxillæ have pointed tips. The forewings are generally of uniform dull or metallic colour with distinct spots (fig. 129). The larvæ live openly on plants, mine in plant-tissues, or feed in cloth and other substances sheltering themselves with cases. The pupal structure is highly variable. In the lower sub-families (*Nepticulinæ*, *Adelinæ*, *Tineinæ*) the pupa is incomplete with three to five free abdominal segments, and comes partly out of its cocoon before emergence, as in all the families hitherto described. But in the higher sub-families (*Gelechinæ Plutellinæ*, etc.) the pupa is obtect with only two free abdominal segments, and does not come out of the cocoon. The Tineidæ are universally distributed; over 700 species are known in our islands, the clothes-moths (see fig. 169) being the most familiar examples.

Pterophoridæ.—The *Pterophoridæ* or PLUME-MOTHS are readily distinguished from all families of Lepidoptera (except the next) by the division of their wings into

"plumes" by deep clefts between the nervures, which are arranged much as in the Tineidæ. There are two clefts in each forewing and three in each hindwing. The larvæ are hairy. The pupæ are incomplete with three or four free abdominal segments; they do not come out of the cocoon but attach themselves by the cremaster.

Orneodidæ.—The *Orneodidæ* contain but a single world-wide genus of Plume-moths, distinguished from the Pterophoridæ by having each wing six-cleft almost to the base. The pupæ agree with those of the succeeding families in being obtect.

In all the succeeding families the pupa is obtect and never comes out of its cocoon before the final moult.

Pyralidæ.—The *Pyralidæ* are a large family of moths of moderate

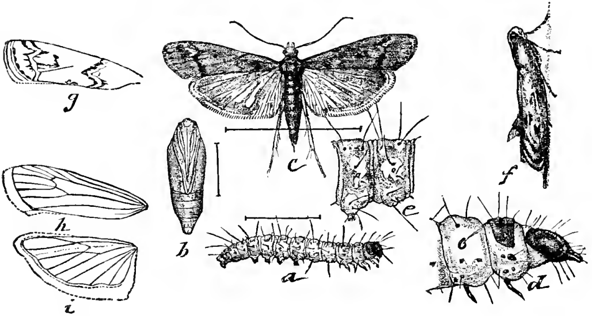


Fig. 130.—*c.* Flour Moth (*Ephestia kühniella*, Zell.), wings spread; *f.* at rest; *g.* forewing, showing plan of markings; *h. i.* neuration; *a.* larva; *b.* pupa, twice natural size; *d.* head and front body-segments of larva; *e.* 2nd and 3rd hind-body segments, more highly magnified. From Riley, Insect Life, vol. 2 (U.S. Dept. Agr.).

or small size. In the forewing the central of the three median nervures arises from the cell nearer to the lower than to the upper median; as in all the succeeding families only two anal nervures are present. In the hindwing there are three anal nervures; the subcostal curves down approaching or touching the radial, and is sometimes connected with it by a cross-nervule. A frenulum is present. The first maxillæ are usually well-developed, with their palps which often attain a great length especially in the sub-family *Crambinæ*. The larvæ have ten pro-legs which are armed with complete circles of hooklets as in the preceding families, while the

pupæ, as in the higher Tineidæ and in all the families yet to be described, are obtect with only two free segments. The forewings of these moths are typically marked with three transverse lines and three discal spots; the family contains both day and night-flying species. The larvæ live in concealed situations, feeding between rolled up leaves or in dry vegetable substances (fig. 130). Examples of aquatic lepidopterous caterpillars—which are very rare—are found in this family whose members are distributed over the whole world.

Thyrididæ.—The *Thyrididæ* are a small family of moths with wide range, most numerous in the tropics, and unrepresented in the British Isles. They are closely allied to the Pyralidæ, but differentiated by having only two anal nervures in the hindwing, and by the absence of palps to the first maxillæ.

Drepanulidæ.—The *Drepanulidæ* are a small family of moths with wing-neuration of the Pyralid type, but there are only one or two anal nervures in the hindwing, and the frenulum is wanting in some genera. The first maxillæ have no palps, and those of the second maxillæ are very small. The forewings are often hooked at the tip. The larva is very characteristic in form having only eight pro-legs; there are none on the hindmost segment which is prolonged into a pointed process, raised up when the insect is at rest. As in all the succeeding families the hooklets on the prolegs do not form a complete circle, but are only developed on the inner edge. The Drepanulidæ are distributed in all parts of the world.

Callidulidæ.—The *Callidulidæ* are a small family of tropical day-flying moths with the Pyralid type of wing-neuration; they may be distinguished from the Drepanulidæ by the long palps (of the second maxillæ) and by the absence of cross-nervules to close the cell in the neuration of the hindwing. They are believed to show affinity with the lowest family of butterflies—the Hesperiidæ which will be described later. The Callidulidæ are confined to India, China, Japan, and the Malayan Archipelago.

Lasiocampidæ.—The *Lasiocampidæ* or EGGAR-MOTHS are large moths with the Pyralid type of wing-neuration, but distinguished from the families just enumerated by the absence of the first maxillæ as well as of a frenulum, and by the presence of double pectination on the feelers in both sexes. The sub-costal nervure of the hindwing is bent downwards, as in the Pyralidæ and allied families, towards the radial system, or is connected by a cross-nervule to the first radial; it gives off, in many genera, a number of accessory nervules towards the costa. The moths of this family are hairy, usually rich brown in the colour of their wings, which have several transverse bars and a central spot. The larvæ with ten prolegs are stout and very hairy, often with prominent tufts on the fore-body. The pupa is enclosed in a hard egg-shaped cocoon of silk and hair. The Lasiocampidæ are distributed in all parts of the world except New Zealand.

Lymantriidæ.—The *Lymantriidæ* or TUSSOCK-MOTHS resemble the Eggars in their hairy bodies and vestigial first maxillæ, but the

feelers are bipectinate only in the males, and the frenulum is nearly always present. The wing-neuration also differs in that the subcostal nervure of the hindwings diverges from a point where it connects with the first radial nervure about the middle of the cell.

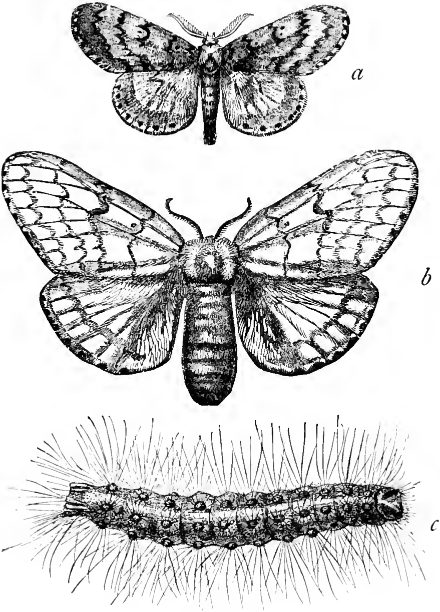


FIG. 131.—"Gipsy" Moth, *Porthetria dispar* (Linn.), Europe. *a.* male; *b.* female; *c.* larva. Natural size. From Riley, Insect Life, vol. 2 (U.S. Dept. Agr.).

The larvæ are exceedingly hairy and are often protected by dense tufts or "tussocks" of prickly, sometimes poisonous, hairs (fig. 131). The pupæ are enclosed in cocoons of silk mixed with the larval hairs.

The distribution of the family is as wide as that of the Eggars. In several instances the females are wingless. They often have a thick tuft of hair at the tip of the hind-body; this serves as a covering for the eggs.

Hypsidæ.—The *Hypsidæ* are a family of tropical moths agreeing closely with the Lymantriidæ in their wing-neuration, but distinguished by the long upturned palps of the second maxillæ whose naked terminal segments reach above the level of the head; the sucking first maxillæ are moreover well-developed. The larvæ are only sparsely covered with hair and the cocoon is slight. The wings are usually brown or yellow in hue, spotted with black or streaked with white. The Hypsidæ range over the tropics of the Old World from Africa to Northern Australia.

Arctiidæ.—The *Arctiidæ* or TIGER-MOTHS form a very large family characterised by the coalescence of the sub-costal nervure of the hindwing with the radial for the basal part of its course, so that it seems to arise from the middle of the cell. In other respects the wing-neuration is much as in the Lymantriidæ. A frenulum is present and the first maxillæ are well-developed. The larvæ are often hairy. Brightly-coloured wings—scarlet, orange or yellow often streaked or spotted with black—are characteristic of this family (fig. 132) which ranges through all parts of the world.

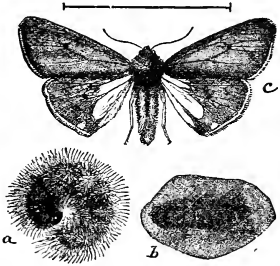


FIG. 132. — *c.* Tiger Moth, *Phragmatobia fuliginosa* (Linn.), Europe. *a.* caterpillar; *b.* cocoon with pupa. Slightly enlarged. From Lugger, Insect Life, vol. 2 (U.S. Dept. Agr.).

Noctuidæ.—The *Noctuidæ* or OWL-MOTHS are the largest and most dominant family of the Lepidoptera. Though characterised by dusky wing-patterns and nocturnal habits, they are nearly allied to the *Arctiidæ* whence they may be distinguished by the sub-costal nervure of the hindwing anastomising with the radial only near the base of the cell. In the forewing the fourth and fifth radial nervures fork from the third which is connected by a cross-nervule with the second. The frenulum is present and the first maxillæ are well-developed. The larvæ are, as a rule, only slightly hairy; ten prolegs are usually present, but sometimes the pairs on the third and fourth hind-body segments are wanting. The pupa is sometimes naked and subterranean, sometimes enclosed in a cocoon made partially of leaves etc. on the

surface of the ground (fig. 133). The Noctuidæ are world-wide in their distribution.

Agaristidæ.—The *Agaristidæ* are a family of large day-flying moths, closely related to the Noctuidæ, though markedly different in aspect, owing to their brightly-coloured wings—often showing scarlet, orange or yellow patches on black ground. In wing-neuration these insects differ from the Arctiidæ, which they rather resemble in appearance, and agree with the Noctuidæ; but they may be structurally distinguished from the latter family by the swollen form of the feelers. The larvæ moreover are hairy. The Agaristidæ are numerous in the tropical parts of Africa, Asia and Australia; a fair

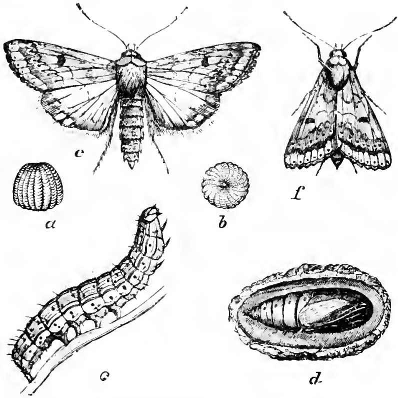


FIG. 133.—*c. f. Heliothis armigera* (Hb.). *e.* larva; *d.* pupa in earthen cell, natural size; *a. b.* egg, highly magnified. From Mally, Bull. 24, Div. Ent. U.S. Dept. Agr.

number of species inhabit southern North America, but very few are found in Central and South America.

Syntomidæ.—The *Syntomidæ* are a family of day-flying moths which resemble the Zygænidæ (p. 232) in aspect, the forewings being much longer than the hindwings. They are, however, structurally, nearer to the Arctiidæ whence they may be distinguished by the absence of the sub-costal nervure of the hindwing. The larvæ are furnished with tufts of hairs, and the pupæ are enclosed in a dense silken cocoon. Dark-coloured wings with clear spots devoid of

scales are characteristic of this family which, very widely spread over the old world tropics, is represented in Europe by two species only; neither of these is certainly known to inhabit the British Islands.

Thyatiridæ.—The *Thyatiridæ* are a small family of moths which differ from the families hitherto considered in the second median nervure of the forewing coming off from the cell midway between the first and third, the other nervures not being, as in the Sesiidæ, Tineidæ, etc., evenly spaced around the cell. In the hindwing the sub-costal nervure bends towards and nearly touches the radial beyond the cell. The frenulum and first maxillæ are well-developed; the feelers are thread-like. In the appearance of the moths and in the form of the larvæ this family is suggestive of the Noctuidæ. It is fairly represented throughout the northern regions but becomes reduced in numbers in the tropics.

Notodontidæ.—The *Notodontidæ* are a family of fairly large moths nearly allied to the Thyatiridæ, but the sub-costal nervure in the hindwing diverges from the radial (wherewith it is sometimes connected by a cross nervule) after the middle region of the cell. The threadlike feelers are sometimes pectinate in the male. The larvæ are usually without pro-legs on the hindmost segment, which is carried erect, and other of the segments often bear hump-like processes. (Hence the name of "Prominents" given to members of this family.) The pupæ are naked and buried underground. The moths are stout in build with hairy feet; the tarsal segments together not longer than the shins; they are found throughout the world except in New Zealand.

Sphingidæ.—The *Sphingidæ* or HAWK-MOTHS are a large family of big, stoutly built moths, closely allied to the Notodontidæ but distinguished by their thick spindle-shaped feelers, which end generally in a hooked tip. The first maxillæ are very long, and the insects suck honey while on the wing, their flight being very powerful. The forewings are long and pointed, always much longer than the hindwings, in which the sub-costal nervure is free throughout its length from the radial and connected therewith with a cross-nervule. The caterpillars, always with ten pro-legs, are destitute of hairs, but a prominent spine or process is usually present on the back of the hindmost segment. The subterranean pupa is not enclosed in a cocoon (fig. 134). The family is world-wide in its range.

Dioptidæ.—The *Dioptidæ* are a small family of day-flying moths with slender bodies, and feelers which are comb-like in the males. The sub-costal nervure of the hindwing is unconnected with the radial; otherwise the neuration is similar to that of the Notodontidæ. The wings of the Dioptidæ are largely destitute of scales, and the moths bear an outward resemblance to certain butterflies of the sub-family Ithomiinæ. They occur only in tropical America.

Geometridæ.—The *Geometridæ* are a very large family of moths

closely related to the Notodontidæ, but distinguished readily by their

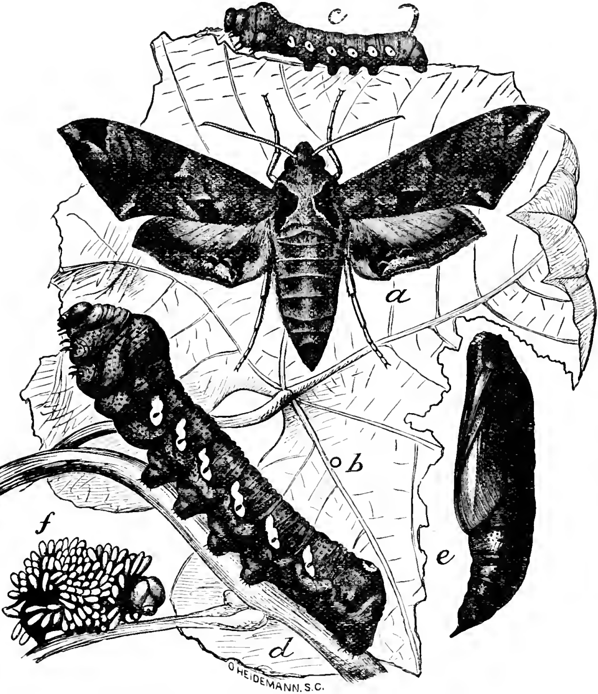


FIG. 134.--*a*. Hawk-Moth, *Philampelus achemon* (Dru.), North America. *b*. egg; *c*. young, and *d*. full-grown caterpillar; *e*. pupa; *f*. caterpillar infested with cocoons of ichneumon-flies. Natural size. From Marlatt, Yearbook, U.S. Dept. Agr., 1895.

more slender build, and their long tarsal segments which are not

hairy. The second median nervure in the forewing is often nearer to the first than to the third, while in the hindwing the sub-costal nervure may closely approach the cell or anastomose with it, being often joined by a cross-nervule to the radial, but it always diverges beyond the cell. The frenulum is sometimes absent. The larvæ are of highly characteristic form, the prolegs on the third, fourth, and fifth hind-body segments being vestigial or absent. That is to say there are only four functional prolegs, and the caterpillars walk by looping the body and so bringing these four prolegs close up to the six thoracic legs. The pupæ are either naked and buried or enclosed in a light cocoon above ground. The family is world-wide in its range (fig. 135).

Epiplemidæ.—The *Epiplemidæ* are a family of moths nearly related to the Geometridæ, but distinguished by the sub-costal nervure of the hindwing being quite free from the radial, and the fifth radial nervure in the forewing being associated with the first median of which it seems to be a branch. The somewhat hairy larvæ differ from those of the Geometridæ in having ten prolegs.

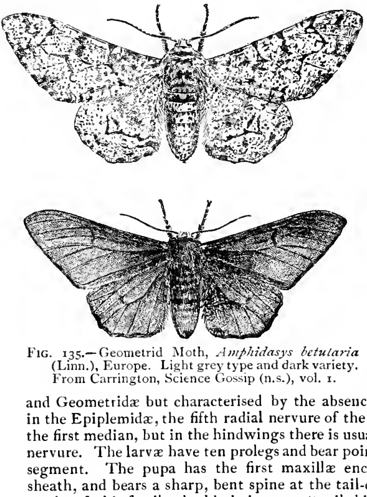
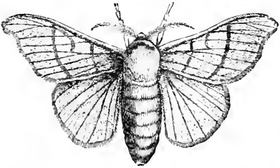


FIG. 135.—Geometrid Moth, *Amphidasys betularia* (Linn.), Europe. Light grey type and dark variety. From Carrington, Science Gossip (n.s.), vol. 1.

Uraniidæ.—The *Uraniidæ* are a small family of large and handsome day-flying-moths, akin to the Epiplemidæ and Geometridæ but characterised by the absence of a frenulum. As in the Epiplemidæ, the fifth radial nervure of the forewing is joined to the first median, but in the hindwings there is usually only a single anal nervure. The larvæ have ten prolegs and bear pointed tubercles on each segment. The pupa has the first maxillæ enclosed in a prominent sheath, and bears a sharp, bent spine at the tail-end. In most of the moths of this family the hindwings are "tailed," and the magnificent green and gold wing-patterns of the species of *Urania* and *Chrysiridia* render them perhaps the most beautiful of all insects. The family is distributed in Tropical America and the West Indies, East Africa and Madagascar, India, the Malayan peninsula and islands, and tropical Australia.

Epicopiidæ.—The *Epicopiidæ* are a remarkable family of large moths comprising only a single genus (*Epicopia*). The first maxillæ are well-developed, the palps of the second maxillæ very small, the feelers bipectinate in both sexes. The frenulum is vestigial. Each cell of the wings is traversed by a nervure (forked in the forewing). In the hindwing the sub-costal is quite free from the radial nervure, and there is only a single anal. The larvæ have skin glands which secrete a white waxy substance forming a dense wool-like clothing. The ample wings are dark except for a few white spots on the hind wings, and the insects are closely like some Papilionidæ which inhabit the districts where they are found—northern India, China, and Japan.

Bombycidæ. — The *Bombycidæ* are a family of moths which agree with the Uraniidæ in the absence of a frenulum, and differ from them in the vestigial condition of the first maxillæ. The palps of the second maxillæ also are greatly reduced. The feelers are bipectinate in both sexes. The forewings are usually pointed at the tip and the lower radial nervures bend downwards; the hindwings have two or three anal nervures. The caterpillars, with ten prolegs, are elongate, not hairy but furnished with dorsal humps on some of the segments, often with a spine on the hindmost. The pupa is enclosed in a dense cocoon of fine silk. The best known larva of this family—that of *Bombyx mori*—is the "common silkworm" (figs. 66, 136). The Bombycidæ are fairly numerous in India, China, Japan, and the Indo-Malayan districts, but scarce in Africa and tropical America. The only European (and British) species which can be referred to this family is *Endromis versicolor*; this must be considered an aberrant form since the second median nervure in the forewing is nearer to the third than to the first.



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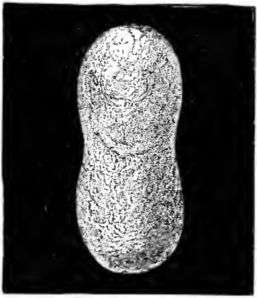

b

FIG. 136.—*a*. Silkworm Moth (*Bombyx mori*, Linn.); *b*. cocoon. Natural size. From Riley, Bull. 9, Div. Ent. U.S. Dept. Agr.

Eupterotidæ.—The *Eupterotidæ* are a family of large moths agreeing with the Bombycidæ in the vestigial condition of the first maxillæ and the bipectinate feelers in both sexes, but differing in possessing a frenulum. There are only four radial nervures in the forewing. In the hindwing there are two anal nervures; the sub-costal nervure is connected with the radial by a cross nervule at the base, but is otherwise free. The larvæ, with ten pro-legs, are furnished with tufts of long hair. The moths of this family are stout in build and brown or ochreous in colour. They are numerous in tropical Africa and Asia; the only European species—the "processionary moth" *Cnethocampa processionea* does not occur in our islands.

Ceratocampidæ.—The *Ceratocampidæ* are a family of large moths with short first maxillæ, the feelers being bipectinate except at the tip in the males, and thread-like in the females. The frenulum is wanting, as in the Uraniidæ, but the fifth radial nervure of the forewing is not stalked from the first median. The caterpillars, with ten pro-legs, are both hairy and spiny. The moths of this family, conspicuously marked with red or yellow variegated patterns, are confined to the warmer parts of America.

Brahmæidæ.—The *Brahmæidæ* are a family of large moths with only one genus (*Brahmæa*). The feelers are bipectinate in both sexes, the first maxillæ fairly developed, and the frenulum wanting. In the hindwing the sub-costal nervure bends towards and nearly touches the radial beyond the short cell; this character separates these moths from all the other families which have lost the frenulum. They have ample rounded wings usually dark brown in colour with lighter undulating lines towards the termen. They are found in Africa, Northern India and Burma, Central Asia and China.

Saturniidæ.—The *Saturniidæ* are a large family of big moths agreeing with the Bombycidæ in most structural features—absence of frenulum, vestigial first maxillæ, bipectinate feelers, and unarmed legs, but distinguished readily by possessing only a single anal nervure in the hindwing, and only three radial nervures in the forewing. The stout caterpillars, with ten pro-legs, are furnished with spine-bearing tubercles. The pupa is enclosed in a dense silken cocoon often of commercial value. The moths are handsomely coloured insects, usually characterised by a clear, unscaled eye-spot at the end of the cell of each wing. The family is distributed in all parts of the world, though represented by a single species (*Saturnia pavonia-minor*) only in our countries. The great Indian *Attacus atlas* is the largest of all the Lepidoptera.

In all the succeeding families the feelers are clubbed and the frenulum is absent. This combination marks off the "butterflies" from the preceding families—"moths"—among which the two characters are never found together (147, 148).

Hesperiidæ.—The *Hesperiidæ* or SKIPPERS are butterflies of small

or moderate size with relatively large body, and broad head with prominent eyes. The feelers, which are widely separated at their bases, usually end in a hook beyond the club. The forewing is usually triangular with pointed tip; the five radial nervures are distinct and evenly spaced, and there is one fully developed anal nervure with the rudiment of another uniting with the first at its base. In the hindwing two anal nervures are present (fig. 137). All six legs are well-developed in both sexes. The caterpillar has a large head and narrow thoracic segments; the pro-legs are provided with complete circles of hooklets a character showing affinity with the lower moths (Pyralidæ, etc.). The pupa is enclosed in a slight silken cocoon. The prevailing coloration of the butterflies is brown, and they are remarkable for their short, jerky flight. The family is almost world-wide in its range, but is unknown in Greenland and New Zealand.

Lycænidæ. — The *Lycænidæ* are a very large family of butterflies, of small or moderate size with comparatively slender bodies; the feelers are inserted close together. In the forewing there are only three or four radial nervures; otherwise the neuration resembles that of the Skippers. The six legs are well-developed in both sexes, except that the front feet are aborted in the males. The larvæ are short and hairy, somewhat like woodlice in shape. The pupa has a marked "waist," is clothed with hairs or bristles, is attached to a pad of silk by the cremaster, and is girdled with a silken thread. The coloration of the butterflies is predominantly blue or copper, and the family is distributed in all parts of the world (figs. 83, 87).

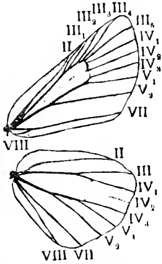

FIG. 137. — Neuration of Wings of *Pamphila palæmon.* Twice natural size. From Grote, Natural Science, vol. 12.

Lemoniidæ.—The *Lemoniidæ* are a family of butterflies nearly allied to the Lycænidæ, which they closely resemble in their wing-neuration. The fore-legs in the males are greatly reduced and useless for walking, though all three pairs are fully developed in the females. The only European member of this family (*Nemeobius lucina*) retains the primitive five branches of the radial system. Most of these butterflies are brilliantly coloured and characteristic of tropical America, a few species only being found in the warmer regions of the Old World.

Libytheidæ.—The *Libytheidæ* are a small family of butterflies easily recognisable by their elongate palps which are almost four times as long as the head and project like a snout. The forewing has a five-branched radial nervure, and forms a broad rectangular prominence at the tip. The larva is cylindrical and slightly hairy, each segment showing a fourfold division; the pupa is suspended only by the cremaster. The family is distributed over all the warmer

regions of the globe except Australia; a single species (*Libythea celtis*) ranges into Southern Europe.

Papilionidæ.—The *Papilionidæ* are a large family of butterflies, all of considerable size. The six legs are fully developed in both sexes. The inner margin of the hindwing is concave and a single anal nervure only runs parallel to it. (In all other families of butterflies two anal nervures are present in the hindwing.) In the forewing the second anal nervure is free from the first and runs to the inner margin (fig. 138). (In all other families of butterflies a second anal nervure, perhaps not corresponding with that in the present family, makes a short basal fork with the first.) The larva is cylindrical, never hairy, but often tuberculate and with a retractile tentacle behind the head. The pupa which has two projecting frontal tubercles, "nose-horns," is fixed by the cremaster, and kept upright by a silken girdle fastening it to a stem of the food-plant. These butterflies — all very handsome in wing-pattern and often with the hindwings prolonged into "tails" at the third median nervure—are distributed in nearly all parts of the world.

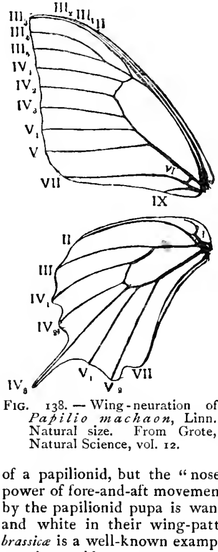

FIG. 138. — Wing-neuration of *Papilio machaon*, Linn. Natural size. From Grote, Natural Science, vol. 12.

Pieridæ.—The *Pieridæ* are a large family of butterflies of medium or large size, with all six legs fully developed in both sexes. They are readily distinguished from the Papilionidæ by the characters indicated above, and from the Hesperiidæ and Lycænidæ by the greater specialisation of the neuration, the nervures not being evenly spaced. In the forewing the first median nervure usually becomes joined with the radial system. The larva is cylindrical and hairy. The pupa is attached both by the tail and by a silken girdle, as that of a papilionid, but the "nose-horn" is single and central, while the power of fore-and-aft movement of the abdominal segments possessed by the papilionid pupa is wanting. The Pieridæ are chiefly yellow and white in their wing-patterns; our "Cabbage White" *Pieris brassicæ* is a well-known example. The family is distributed throughout the world.

Nymphalidæ.—The *Nymphalidæ* are the largest and most dominant of the butterfly-families. They are characterised by the reduction of the fore-legs in both sexes so as to be useless for walking; the tarsal

segments are wanting and the short shins are clothed with long hairs, whence the name "brush-footed butterflies" sometimes applied to the family. The neuration is of the same type as in the Pieridæ but varies in detail in the different sub-families into which the group has been divided up. The larvæ vary much in outward form, being armed with formidable spines in some genera, and smooth or hairy in

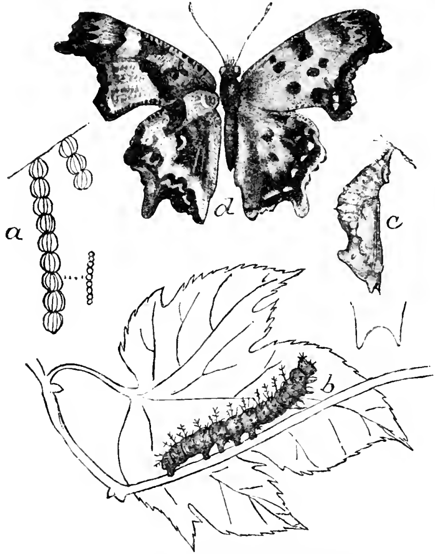

Fig. 139.—Nymphalid Butterfly (*Polygonia comma*, Harris), N. America. *a*. egg-chain, magnified; *b*. caterpillar; *c*. pupa; *d*. imago (upper side of wing right, under side left). Natural size. From Howard, Bull. 7 (n.s.), Div. Ent. U.S. Dept. Agr.

others. The pupa, which has, as in the Papilionidæ, a double nose-horn, is simply hung by the cremaster from a pad of silk, without any girdling thread. As the divisions of the Nymphalidæ are often treated as separate families, a short summary of their characters is given.

The *Danainæ* have the anal nervures of the forewing forked at the base, the cells in both wings closed, and the front feet of female thickened. The larvæ are smooth with fleshy processes. They range all over the warmer parts of the world, and far north in America, though not in Europe.

The *Ithomiinæ* differ from the Danainæ in the slender front feet of their females and the larvæ are covered with small elevations. The wings in many genera are almost destitute of scales. The sub-family is confined to tropical America.

The *Acræinæ* are narrow-winged butterflies, of brown and reddish-brown colour with the cells of the wings closed and the anal nervure simple; the palps are thick and hairy. The larvæ have long branching spines. The Acræinæ occur in tropical America, Africa, India, and Australia.

The *Heliconiinæ* are brightly-coloured, narrow-winged butterflies, distinguished from the Acræinæ by the palps which are compressed and scaly at the sides, and hairy in front. The larvæ have branched spines. These insects are confined to tropical America.

The *Nymphalinæ* are a very large sub-family of world-wide distribution characterised by the open cells of the wings; at most a vestigial discocellular nervule is present. The larvæ are spiny or smooth (figs. 88, 89, 139).

The *Morphinæ* are large butterflies with the cells closed in the fore-wings and open in the hind-wings. The larvæ are smooth or hairy with the tail-segment forked. This group is confined to tropical America, India, and Indo-Malaya.

The *Brassolinæ* are robust butterflies with the cells closed in both wings, which are usually adorned with large "eye-spots" beneath. These insects, which have larvæ with a forked tail-segment, are confined to tropical America.

The *Satyrinæ* have compressed palps with long bristly hairs, the cells closed in all the wings, and the sub-costal nervure greatly thickened (fig. 90). The larvæ have a forked tail-segment and are smooth or clothed with short hairs. The sub-family is world-wide in distribution.

ORDER 14.—DIPTERA.

Structure.—The Two-winged Flies which make up this order are sharply marked off from all other insects by the reduction of the hind-wings to stalked knobs ("balancers" or *halteres*), the fore-wings alone being of use for flight; their mechanism is however so perfect that the motion of Diptera through the air is perhaps more accurate than that of any other insects. The head is usually very convex with large

eyes, and the neck is so slender and flexible that it can be turned almost through a complete circle. The feelers vary greatly in form in the different groups. The mandibles and blades of the first maxillæ, if present, are piercing stylets, and the epipharynx is often modified for the same purpose; the hoods of the second (or first ?) maxillæ form a sucker. The fore-body

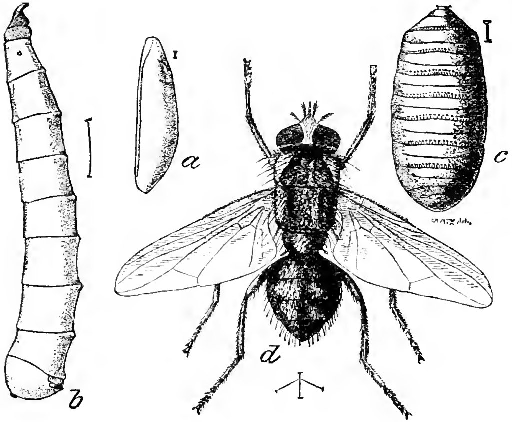

FIG. 140.—*d.* Horn-fly (*Hæmatobia serrata*, Rob.-Desv.), Europe; *b.* larva; *c.* puparium, magnified 8 times; *a.* egg, magnified 20 times. From Riley, Insect Life, vol. 2 (U.S. Dept. Agr.).

segments are fused into a firm capsule, the prothorax being greatly reduced and largely concealed above by the mesothorax; the mesoscutum and mesocutellum form most of its upper aspect. The legs are usually slender and often spiny, the feet with five segments

end in two claws and a well-formed two or three-lobed pad. The wings are membranous, with not more than seven longitudinal nervures, a sub-costal (two sometimes), a radial, an ulnar,[1] two medians, and two anals; the forking and bending of these nervures, and the presence of a variable number of cross nervules lead to the formation on the wing area of cells, which are never very numerous. A small rounded part of the anal area at the base of the wing is often sharply marked off. Behind the wings a pair of scales — small membranous plates — are present in some families. The hind-body may possess eight evident segments, but in some families only four or five are visible; prominent male claspers are present in some groups, and the ovipositor of the female often consists of the reduced and retractile hinder abdominal segments (fig. 141) (4, 150, 151).

FIG. 141.—Ovipositor of Warble-fly (*Hypoderma bovis*, D. G.). *a.* from side; *b.* tip from beneath. Magnified. From Riley, Insect Life, vol. 2 (U.S. Dept. Agr.).

Development, and Habits.—The Diptera pass through a complete metamorphosis; the larva is in all cases eruciform, a grub or maggot destitute of true legs, though prolegs and other secondary organs of locomotion are often present. In many families the larvæ are aquatic. The pupa (fig. 142) is sometimes free, but usually incomplete or obtect, though the cohesion of the appendages is less marked than in the pupæ

[1] Many systematic writers on the Diptera call the third nervure (ulnar) the cubital; it is really a branch of the radial. The lower median is probably the true cubital.

of the higher Lepidoptera. It is rarely enclosed in a cocoon but lies buried in the ground, floats in the water, or is protected by the last larval skin which, separating from the pupa-skin, remains around it as a hard case (*puparium*) (fig. 140 *c*). Flies and their larvæ live in the most diverse manner. Some flies attack back-boned animals and suck their blood, some prey on smaller insects, some suck honey, and some find their food in decaying animal and vegetable matter. A large number of dipterous larvæ eat refuse or carrion, many feed inside growing vegetable tissues, and some prey or are parasitic on other insects (**4**, **151**).

Classification.—The Diptera probably outnumber any of the other orders in individuals and species, including many families, which were formerly grouped in two divisions founded mainly on the form of the feelers (**150**). The nature of the larva and the way in which the pupa-skin splits open are now considered of greater importance, and the Diptera are often divided into two sub-orders founded on this character (**149**, **151**, **153**). The Fleas are however such a very aberrant parasitic group of Diptera that they seem fully entitled to rank as a third sub-order. Indeed by some writers (**95**, **97**) they are reckoned as a distinct order (Aphaniptera or Siphonaptera).

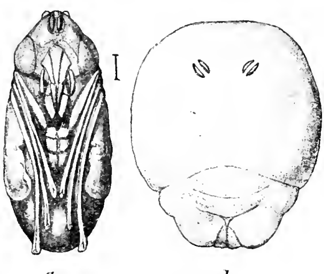

FIG. 142.—*a*. pupa of House-fly (*Musca domestica*), magnified 10 times; *b*. tail-end of young larva, more highly magnified. From Howard, Bull. 4 (n.s.), Div. Ent. U.S. Dept. Agr.

SUB-ORDER A. APHANIPTERA.

The **Aphaniptera** or FLEAS are characterised by the entire absence of wings, and the flattening of their bodies from side to side. The feelers are short and usually hidden in pits on either side of the head; they seem to have four segments, but the last is ringed and really represents a number of segments fused

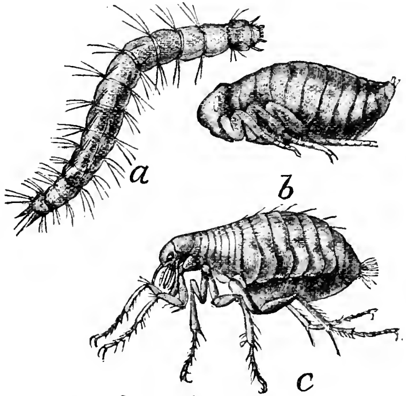

FIG. 143.—*c.* Common Flea (*Pulex irritans*, Linn.), Europe, etc.; *a.* larva; *b.* pupa. Magnified. From Osborn, Bull. 5 (n.s.), Div. Ent. U.S. Dept. Agr.

together. The only eyes are a few simple ocelli. The jaws are powerful, piercing organs, the mandibles and hypopharynx being developed as hard toothed stylets; the palps of both pairs of maxillæ are present. The legs are long and powerful, owing to the great size of the haunches, specially adapted for leaping. The larvæ are soft white grubs with well-chitinised

heads and with bundles of hairs on the body-segments; they live in dust (fig. 143). The pupa is free and shows great likeness to the adult (fig. 143 *b*); it is enclosed in a light cocoon of spun silk and dust. The adult Fleas suck blood from birds and mammals. They may be divided into two families (149).

Pulicidæ.—The *Pulicidæ* comprise the best known fleas. There are from three to five segments in the palps of the second maxillæ; the head is relatively small; and the hind-body is elongate and does not become greatly swollen in the pregnant female. The Common Flea (*Pulex irritans*) (fig. 142 *c*) it is a too well-known example of this family, which is world-wide in its range.

Sarcopsyllidæ.—The *Sarcopsyllidæ* or "JIGGER-FLEAS" have large heads and ten-segmented palps to the second maxillæ. The hind-body is short but becomes immensely swollen in the pregnant female who usually burrows after fertilisation into the skin of her host, causing a painful tumour. The larvæ on hatching escape from the host's body. This family is confined to tropical regions (fig. 144).

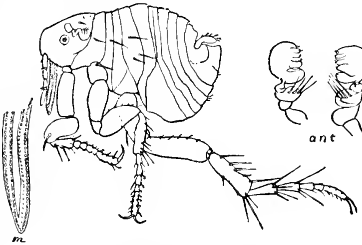

FIG. 144.—Hen Flea (*Sarcopsylla gallinacea*), Western India, etc. Male, magnified; *ant.* feelers; *m.* palps, highly magnified. From Packard, Insect Life, vol. 7 (U.S. Dept. Agr.).

SUB-ORDER B. ORTHORRHAPHA.

The **Orthorrhapha** are winged Diptera, the skins of whose pupæ (and puparia when present) split open along the back in the manner usual in insects to allow the imago to escape. There is a distinct chitinous head-capsule in the larva. The flies of this sub-order may be divided into two groups according to the form of the feelers, and the characters of these groups serve to separate the families con-

tained in them from those of the next sub-order (Cyclorrhapha, p. 262).

Group A. Nematocera.

The **Nematocera** comprise those Diptera in which the slender feelers have at least seven segments, and usually many more: hence their name: "Thread-horns" (149, 150).

Cecidomyidæ.—The *Cecidomyidæ* or GALL-MIDGES are a large family of small slender flies. The head is relatively large, the compound eyes lunate and not hairy, the simple eyes almost always absent. The feelers have thirteen segments in the female and twenty-four at least in the male; the segments are bead-shaped, and bear long hairs arranged in whorls. The mesoscutum shows no transverse suture. The hind-body is elongate and has eight evident segments; in the male prominent claspers are present, and in the female a pointed ovipositor. The legs are long, the haunches short, and the shins without spines. The wings have never more than six longitudinal nervures and hardly any cross-nervules; the costal nervure is continued around a great part of the wing margin, and the wing area is hairy or scaly. The larvæ are fleshy, spindle-shaped maggots, remarkable among insects in having fourteen segments behind the small head; between the first and second of these is a peculiar horny process. The maggots live in plant tissues which usually become deformed into various kinds of galls owing to the irritation set up by the insects; the obtect pupæ are enclosed in the dried larval skin. The "Hessian-fly" (*Cecidomyia destructor*) so destructive to corn crops is a well-known member of this family, which contains a multitude of species distributed over the whole world.

Mycetophilidæ.—The *Mycetophilidæ* or FUNGUS-MIDGES are a very large family nearly allied to the Cecidiomyidæ, but distinguished by the presence of simple eyes on the head, by the segments (ten to sixteen in number) of the feelers being cylindrical, by the long haunches, by the shins, clothed with stiff hairs and bearing spines at the tip. The wing-neuration is simple; there is usually but a single cross-nervule linking the sub-costal nervure to the radial. The larvæ are elongate fleshy maggots living and feeding in vegetable refuse or fungi; they spin a cocoon in which the pupa rests. In some genera the pupa has the prothoracic spiracles on raised processes or horns. The Fungus-midges are exceedingly numerous, and are world-wide in their range.

Bibionidæ.—The *Bibionidæ* are a family of moderately large flies of somewhat stout build. The feelers are relatively much shorter than in the preceding families, seldom longer than the head and

composed of eight to twelve segments. The compound eyes are large, in the male occupying most of the head-area; there are three simple eyes. The wings are broad, with six longitudinal nervures and only one or two cross-nervules; the legs are short and stout, the shins having often large spines, and the feet three terminal pads. The larvæ are somewhat flattened and spindle-shaped maggots, the body-segments bearing tubercles and bristles; they feed on roots of living plants or in decaying vegetable matter. Most of the Bibionidæ are dull black in colour.

Simuliidæ.—The *Simuliidæ* or SAND-MIDGES are a small family comprising only a single genus (*Simulium*). The head is partly overhung by the thorax; the compound eyes of the male are enormous and globular, but there are no simple eyes, and the eleven-segmented feelers are thick and only slightly longer than the head. The wings are relatively large with seven longitudinal nervures but only a single cross-nervule; the legs are stout and unarmed. The upper lip of the female is developed as a hard piercer, and the insects, occurring in swarms in some parts of the world, cause great annoyance to men and domestic animals by their attacks, as they suck blood greedily. The larvæ (fig. 160, *a*, *b*) live in water, attached to stones or rushes by a sucker at the tail-end. In addition to the feelers and the usual jaws, the head carries a most remarkable pair of jointed appendages which bear long flexible hairs; the motion of these brings organic food-particles within reach of the mouth. The pupa (fig. 160, *c*, *d*), has branching gill-filaments on the prothorax, and rests in a pouch-shaped, silken cocoon (fig. 160, *e*) (**170**). The Simuliidæ are generally distributed.

Chironomidæ.—The *Chironomidæ* or MIDGES are distinguished from the Simuliidæ by their elongate feelers and legs, and narrow wings; from the Cecidomyidæ (with which they agree in the absence of simple eyes) they are distinguished by the costal nervure reaching only to the wing-tip. The head is small and largely hidden beneath the thorax, and the feelers have from six to fifteen segments which, especially in the males, bear whorls of hairs, often exceedingly long. The larvæ live in water; they are long cylindrical grubs often of a bright red colour ("blood-worms") with paired sucker-feet on the second and last (thirteenth) body-segments, and, usually, thread-like gills on the eleventh and twelfth. They often form sandy tubes for protection. The pupa is not enclosed in a cocoon; it breathes by paired gill-threads on the prothorax, these have the form of feathered stars. The Chironomidæ are world-wide in their range; several genera live on the sea-shore and have marine larvæ (**169, 170**).

Psychodidæ.—The *Psychodidæ* are a family of very small, densely hairy, moth-like flies. The small head is almost hidden under the thorax; the feelers have sixteen segments, and there are no simple eyes. Only six or seven abdominal segments are visible, but the male claspers are very prominent. The wings have seven longitudinal nervures, but the cross-nervules are all near the wing-base. The

larvæ live in decaying vegetable matter. The family is widely distributed.

Culicidæ.—The *Culicidæ* or GNATS are distinguished from the preceding families by the well-developed wing-neuration: seven longitudinal nervures are present, several of which are forked, and there are cross-nervules in the middle region of the wing-area. The body, the wings and the very slender legs are hairy and scaly (fig. 9, *g*, *h*). The long feelers have fifteen segments which are clothed with whorled hairs, those of the male being very long and dense (fig. 9, *b*). The jaws are greatly elongated in some genera—such as *Culex* which includes the common gnats and mosquitoes—and the sharp, horny mandibles and hypopharynx of the females can inflict a severe bite on the mammals whose blood they suck; in the male of these insects the palps are remarkably long and hairy. The larvæ live in water; they are active grubs with large head and thorax and slender flexible hind-body, by the lashing of which they swim quickly through the water (fig. 72 *a*). They usually hang head downwards from the surface, taking in air through a special tube which branches from the hinder end of the body and is guarded by a valve of leaf-like plates. The incomplete pupa (fig. 72) breathes through a pair of respiratory tubes on the prothorax; the openings of these rest in contact with the surface as the pupa floats freely (170). The Culicidæ are world-wide in their range.

Tipulidæ.—The *Tipulidæ* or CRANE-FLIES ("Daddy-long-legs") are easily distinguished from all other Nematocera by their large size, their exceedingly long legs, their wings with the longitudinal nervures all present and mostly forked and with numerous cross-nervules, and by a distinct transverse suture across the mesoscutum. The head is prominent and rounded, without simple eyes; the feelers have from six to nine segments. The hind-body is long, cylindrical or spindle-shaped with seven or eight visible segments, with prominent claspers in the male and ovipositor in the female. The larvæ of the typical Crane-flies (*Tipulinæ*, in which the terminal segment of the palp is long and whip-shaped) are stout, tough-skinned grubs ("leather-jackets") which live underground and feed on roots; the pupa partially raises itself out of the ground to allow the fly to emerge. Among the *Limnobiinæ* (distinguished from the Tipulinæ by the terminal palpal segment being shorter than the last but one as well as by neurational details) several genera have aquatic larvæ. The Crane-flies are numerous in genera and species, and are found throughout the world.

Rhyphidæ.—The *Rhyphidæ* are a small family of flies distinguished from the Tipulidæ by the absence of the suture across the mesoscutum, and from all other families of Nematocera by the presence of a discoidal cell in the wing area, formed by a cross-nervule between the two median nervures towards the wing margin. The larvæ feed on decaying vegetable matter. The family only includes a single genus of which one species (*Rhyphus fenestralis*) is not uncommonly found on the windows of houses.

Group B. Brachycera.

The **Brachycera** include those Orthorrhapha in which the feelers have never more than five segments and usually only three. The larvæ are mostly elongate, fleshy maggots with small retractile head. The insects included in this section may almost all be known in the imaginal state from those of the suborder Cyclorrhapha (see below p. 262) by the long bristle (when present) on the third (last) antennal segment being situated at the tip, instead of on the upper surface. (Some of the Conopidæ and the Platypezidæ among the Cyclorrhapha and certain genera of the Dolichopidæ belonging to the present group do not conform to this rule; see the characters of these three families below, pp. 261-3.) The wing-neuration is usually complex, the longitudinal nervures forking often, and several cross-nervules being present (**150, 151, 152**).

Stratiomyidæ.—The *Stratiomyidæ* are a family of stoutly-built flies often brightly coloured. The head is as broad as the thorax, and the three-segmented feelers have the terminal segment distinctly ringed (as if formed by the fusion of several segments) with a claw or bristle at the tip. The mesoscutellum is often spinose. The moderately long and slender legs are without stiff bristles or spines. The wings have the costal nervure reaching only to the tip. The larvæ live in damp places or in water. That of *Stratiomys* is elongate and spindle-shaped with a small retractile head and a breathing opening at the tail guarded by branched threads arranged star-wise. The pupa is incomplete and remains, either buried in the earth or floating in the water, within the dried larval skin, which serves as a protection. The Stratiomyidæ are numerous and generally distributed.

Xylophagidæ.—The *Xylophagidæ* are a small family of flies resembling the Stratiomyidæ in the ringed third antennal segment, but there is no terminal claw or bristle, and the scutellum is not spined. The head is as broad as the body which is somewhat slender in build. The legs have no stiff bristles, but the shins bear spines at the tip. The costal nervure is continued all round the wing-margin. The flies of this family suck the juices of plants and are often observed to feed on the sap of trees.

Tabanidæ.—The *Tabanidæ* or Gad-flies are usually large robust

flies with broad head, pointed in front and concave behind, fitting closely to the thorax. The feelers are three-segmented with ringed terminal segment, the eyes very large, in the male occupying nearly all the head-area. The thorax is flat above, and the scutellum not spined. The costal nervure is continued around the wing-margin. The legs are long and stout, sometimes hairy, but without stiff bristles. The hind-body is large and broad with seven visible segments. Mandibles and maxillæ are developed as formidable piercing organs, and the flies suck the blood of mammals; the species of *Tabanus* cause great annoyance to cattle, and those of *Hæmatopota* to men and horses. The larvæ are elongate, fleshy maggots with small retractile heads; they live in damp earth and feed on snails, slugs, and beetle-grubs. The incomplete pupæ lie freely in earthen cells. The Tabanidæ are generally distributed.

Leptidæ.—The *Leptidæ* or SNIPE-FLIES are of moderate size clothed with short, scanty hair. They have the thorax very short and broad, the hind-body long and stout, the legs slender and the wings large. The feelers have three segments, whereof the last is short and conical, or round with a long, feathered bristle at the tip. The proboscis is long, thick, and cylindrical pointing downwards from the head and the Leptids prey therewith on small insects. The larvæ live underground; and the pupæ lie freely in earthen cells. The family is generally distributed.

Asilidæ.—The *Asilidæ* or HAWK-FLIES are large robust flies with a dense, hairy covering, and differing from the preceding families in bearing large stiff bristles. The head is short and broad and the eyes very convex; the feelers have three segments, the last with or without bristle or claw at the tip. The mandibles and blades of the first maxillæ are strong piercers, and the sucker is short. The thorax is markedly narrowed in front, the head therefore appearing very prominent. The long, tapering hind-body has eight visible segments. The wings are large with forked ulnar nervure and a discoidal cell, while the legs are stout and moderately long. The flies prey on weaker insects, but the larvæ live like those of allied families in damp earth. The family is generally distributed.

Midasidæ.—The *Midasidæ* are another family of large flies of prey, resembling the Asilidæ in aspect but distinguished readily by the four or five-segmented feelers. The family is widely distributed in the tropics, but only a single species reaches southern Europe. Some of the larvæ are known to be parasitic on longhorn beetles.

Bombyliidæ.—The *Bombyliidæ* are a family of flies which resemble humble-bees in appearance. The head is small, the body usually robust and clothed with woolly hair. The three-segmented feelers have a bristle or claw at the tip; the mandibles and blades of the first maxillæ are piercing organs, and the sucker is usually very long. The legs are slender and weak, the wings relatively large with forked ulnar nervure and many cells. The larvæ live in damp earth, and the flies suck honey from flowers. The family is generally distributed.

Therevidæ.—The *Therevidæ* are a rather small family distinguished from the Bombyliidæ, to which they are allied, by having five hind-marginal cells on the wings instead of three. The head is broad and bluntly conical, and the three-segmented feelers have always an apical claw; mandibles and blades of first maxillæ act as piercers. The hind-body with seven visible segments is elongate and pointed behind. The legs are very slender, a character which separates these flies from the Asilidæ. From the Leptidæ the claw (instead of a bristle) at the tip of the feelers distinguishes them, as also the presence of two adhesive pads (instead of three) on each foot. The larvæ live in fungi and rotting wood. The flies prey upon weaker insects, which they capture by lurking among herbage and suddenly darting out.

Empidæ.—The *Empidæ* are a large family of predaceous flies with somewhat slender bodies almost without hairy covering. The head is comparatively small, and the form of the feelers and jaws is like that of the allied families. The hind-body has five to seven visible segments, and the male's claspers or the female's pointed ovipositor are usually conspicuous. The haunches are unusually long in some genera, in others the hind-thighs are very elongate or greatly thickened, or the first tarsal segment very broad. The family is widely distributed.

Nemestrinidæ.—The *Nemestrinidæ* are a family of rather large flies of robust build somewhat like Tabanidæ or Bombyliidæ in aspect. From the former they may be known by the unringed terminal segment of the feelers, from the latter by the possession of five hind-marginal cells on the wing. They are widely distributed in tropical Asia and Africa and range northwards into southern Europe.

Dolichopodidæ.—The *Dolichopodidæ* are a very large family of small, slender flies mostly of bright metallic colours. The third segment of the feelers has in some genera, the bristle at the tip, in others on the upper edge as among the Cyclorrhapha. The members of this family may however be distinguished by the absence of the cross-nervule usually present toward the base of the wing between the two median nervures; the hinder basal cell thus becomes fused with the discoidal cell. The third longitudinal nervure is not forked, as in the preceding families of Brachycera. The larvæ live in damp earth, among trees, or under bark. The flies prey upon weaker insects; they are very numerous and are often to be found near water, sometimes running over the surface. The family is generally distributed.

Lonchopteridæ.—The *Lonchopteridæ* are a family of small flies characterised by their lance-shaped wings with a sharp angle at the tip. The neuration is not well-developed, as the ulnar nervure is not forked and there are no cross nervules in the middle area of the wing The head is oval with prominent eyes, the thorax, hind-body and legs long. The family is poor in genera and species.

Sub-Order C. Cyclorrhapha.

The **Cyclorrhapha** are those Diptera whose larvæ are, for the most part, degraded maggots with no distinct head-capsule, the front end of the body being armed with hook-like jaws and capable of protrusion or withdrawal. The pupa is enclosed in the dried larval skin which hardens into an egg-shaped puparium; this opens by the splitting-off of a circular lid at the head end, and allows the developed imago to escape. The flies have short, three-segmented feelers; the third segment is far the largest and bears a long bristle (fig. 146 *c*), and (except among the Platypezidæ) this bristle springs from the upper edge of the segment. (In some of the Conopidæ, see below, p. 263, the third antennal segment bears a terminal claw.) (**150, 151.**)

Platypezidæ.—The *Platypezidæ* are a small family of little flies, mostly black in colour, which are distinguished from all the rest of the Cyclorrhapha (except a few of the Conopidæ) by having the antennal bristle at the tip of the third segment. From the earlier families in the brachycerous division of the Orthorrhapha the Platypezidæ may be distinguished by the unforked ulnar nervure. Their rounded wings separate them readily from the Lonchopteridæ, and the presence of rounded lobes, marked off from the wing area near the base, from the Empidæ and Dolichopidæ. The hind-feet are usually very broad; this also serves as a distinction. Some larvæ of the family are known to live in fungi; they have a small but distinct head, and paired air-openings on the first and last body-segments.

Pipunculidæ.—The *Pipunculidæ* are a small family of flies characterised by a roundly conical head which is broader than the thorax, by a long anal cell (the cell between the fifth and sixth longitudinal nervures) reaching, or almost reaching, the wing margin, and usually by a narrow cylindrical hind-body brightly marked with yellow. The larvæ, which resemble in structure those of the last family, live parasitically on other insects.

Syrphidæ.—The *Syrphidæ* or Hovering-flies are a very large and important family, readily distinguished from all other Diptera by the presence of a slender additional longitudinal nervure (*vena spuria*) between the third and fourth. They agree with the Pipunculidæ in having a long anal cell, and in being usually brightly variegated with yellow on the hind-body. Many of them, especially some of the

more hairy species (*Volucella* and *Eristalis*) are strikingly like wasps and bees. The head is large with very well-developed eyes; the mandibles and first maxillæ are present as stylets, and the sucker is fairly prominent. The larvæ, which have no distinct head-capsule, vary much in their outward form and manner of life. Some (*Syrphus*) are fairly active, tapering grubs, living openly on plants and preying on aphids; others (*Eristalis*) are cylindrical maggots with sucker feet, feeding on organic matter in foul water, and breathing through a single spiracle situated at the tip of a long telescopic "tail"; others (*Volucella*) are short maggots with pointed tubercles on the segments, living in the nests of wasps and bees where they act as scavengers or prey on the Hymenopterous grubs; others again (*Cheilosia*) feed in fungi or decaying vegetable matter. The family is very numerous in genera and species, and world-wide in its range.

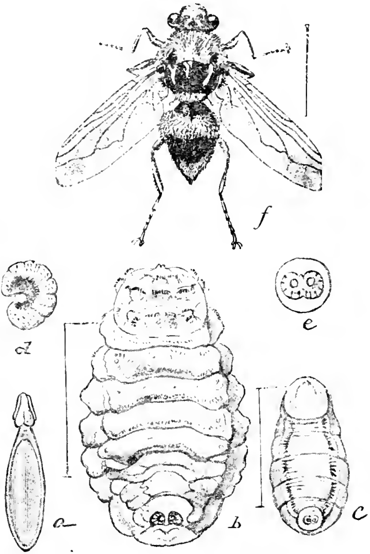

FIG. 145.—*f*. Warble-fly (*Hypoderma bovis*, D.G.), twice natural size; *a*. egg, magnified 20 times; *d*. newly-hatched larva, magnified; *b*. full-grown larva, twice natural size; *e*. its anal spiracles, more highly magnified; *c*. puparium, slightly enlarged. From Riley (after Brauer), Insect Life, vol. 2 (U.S. Dept. Agr.).

Conopidæ.—The *Conopidæ* are another family of brightly-coloured wasp-like flies distinguished by the very large swollen head, thin horny sucker, and total absence of large bristles on the hind-body segments. The members of one sub-family (*Conopinæ*) have the antennal segments long and straight with a jointed claw at the tip of

the third. This is a character of the brachycerous Orthorrhapha, but the form of the hind-body, narrow at the base and broadly conical behind, in conjunction with the very broad head, separates them from all the families of that group.

Œstridæ.—The *Œstridæ* or Bot-flies may be distinguished from the preceding families of the Cyclorrhapha by having the anal cell of the wings short, confined by a cross-nervule to a small part of the basal area. They are hairy, bee-like flies with comparatively small

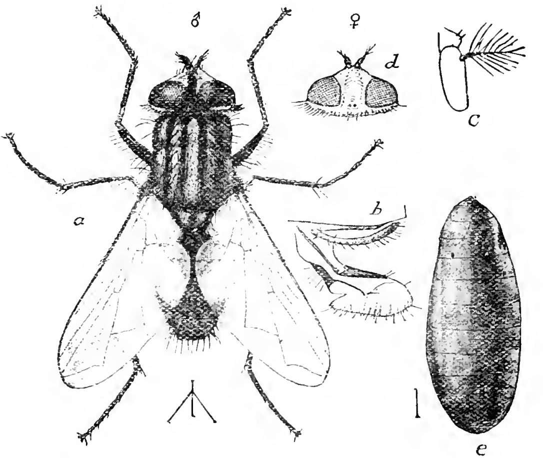

Fig. 146.—House-fly (*Musca domestica*, Linn.), Europe, etc. *a.* Male; *d.* head of female; *e.* puparium, magnified 9 times; *c.* 2nd and 3rd segments of feeler; *b.* maxillæ (proboscis) and palps, more highly magnified. From Howard, Bull. 4 (n.s.), Div. Ent. U.S. Dept. Agr.

eyes, and with the jaws and their palps reduced to a vestigial condition. The hind-body has six visible segments; the female has a long tubular ovipositor composed of the hinder segments. The larvæ are stout, barrel-shaped, tough-skinned maggots armed with numerous spines; they live parasitically in the bodies of mammals in which the female lays her eggs. Some species inhabit the nasal cavities, others the food-canal, others, like the warble-fly (*Hypoderma*

bovis) of the Ox (fig. 145), live just beneath the skin through which they bore holes when full fed and bury themselves in the ground for the pupal stage. The family is not numerous in genera and species but is very widely distributed.

The three next families of the Cyclorrhapha may be distinguished from the Syrphidæ and allied families by the short basal cell of the wings, and from the Œstridæ by the presence of well-developed sucker and palps. They form the group *Muscaria* and include the most familiar flies.

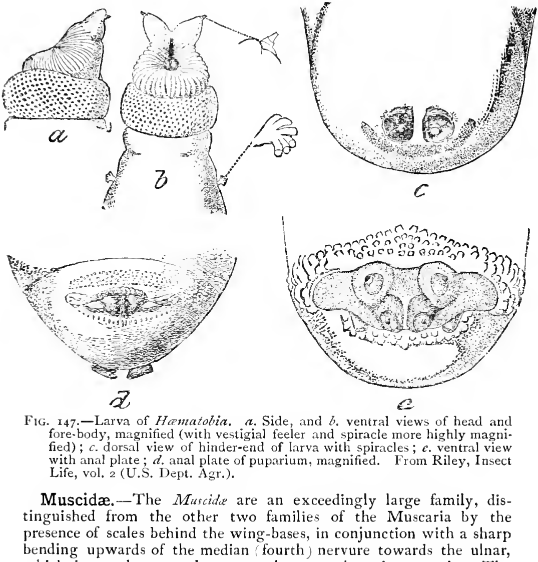

FIG. 147.—Larva of *Hæmatobia*. *a*. Side, and *b*. ventral views of head and fore-body, magnified (with vestigial feeler and spiracle more highly magnified); *c*. dorsal view of hinder-end of larva with spiracles; *e*. ventral view with anal plate; *d*. anal plate of puparium, magnified. From Riley, Insect Life, vol. 2 (U.S. Dept. Agr.).

Muscidæ.—The *Muscidæ* are an exceedingly large family, distinguished from the other two families of the Muscaria by the presence of scales behind the wing-bases, in conjunction with a sharp bending upwards of the median (fourth) nervure towards the ulnar, which it touches, or almost touches, on the wing-margin. The Muscidæ are, for the most part, ash-coloured or metallic flies of moderate size, often with many stiff bristles; only four to six abdominal segments are visible (fig. 146). The larvæ are white, fleshy maggots,

broad at the hinder end and tapering forwards. They breathe by means of large paired spiracles (fig. 147 *c*) on the tail-segment; the fan-shaped spiracles on the prothorax (fig. 147 *b*) are probably not used by the maggot, but air-openings in the same region become functional in the pupa. The maggots in many genera are hatched out within the mother's body; they feed on decaying animal and vegetable substances, or are parasitic in caterpillars and other insects wherein the mother-fly lays her eggs. The Muscidæ are world-wide in their range. The four divisions here characterised as sub-families are regarded as families by most modern authors.

The *Tachininæ* have strong bristles (*macrochetæ*) on each of the four to six hind-body segments, and the antennal bristle is naked or only feebly pubescent. The larvæ are parasitic on caterpillars. The *Dexinæ*, which also have parasitic maggots, are characterised by strong bristles on their four-segmented hind-body and an antennal bristle feathered to the tip. The *Sarcophaginæ* also have strong bristles on the four-segmented abdomen; the antennal bristle is feathered for its basal half, and the larvæ feed on decaying animal matter. The *Muscinæ* have the hind-body devoid of stiff bristles, and the antennal bristle is feathered throughout its length.

Anthomyidæ.—The *Anthomyidæ* agree with the Muscidæ in having scales behind the wings, but may be readily distinguished by the ulnar nervure having a straight or evenly curved course, never bending upwards at a marked angle towards the radial. The antennal bristle may be naked or feathered, and four or five hind-body segments are visible. The larvæ are flattened maggots often with pointed tubercles on the segments; like the maggots of the Muscidæ, they breathe by a pair of tail-spiracles. They feed in decaying animal or vegetable substances, or devour living plant tissues. The family is very numerous in genera and species and is universally distributed (154).

Tephritidæ.—The *Tephritidæ* differ from the two preceding families in the absence of scales behind the wings; the neuration in most of the genera resembles that of the Anthomyidæ. The very large section here treated as a single family was formerly regarded as a sub-family of the Muscidæ (Acalypteræ); by many modern authors, on account of the structural details showing great variation, it is broken up into some fifteen distinct families. The larvæ are mostly fleshy, tapering maggots, which live on decaying matter or feed in living plant tissues, while some are parasitic on other insects. The family is world-wide in its range.

Phoridæ.—The *Phoridæ* are a family of small flies characterised by the insertion of their short feelers close to the edge of the mouth. The legs have long haunches, wide thighs, and very long basal segments to the feet. The wings are relatively large and have a very characteristic neuration; two thick nervures—sub-costal and radial—run close to the costa for about half its length and then

give off from three to five very slender nervures which reach the wing-margin. The hind-body is short, tapering, and bent downwards; six or seven segments are visible. The larvæ mostly live as parasites on snails and insects.

The three concluding families of the Diptera are degraded, parasitic flies in which development up to the pupal stage is completed within the mother's body; they were therefore formerly classed as a distinct sub-order (Pupipara). The jaws are much less modified than in Diptera generally (hence the name Eproboscidea sometimes applied to the group); parts of the second maxillæ are recognisable as paired lobes at the base of the sucker (**155**).

Hippoboscidæ.—The *Hippoboscidæ* are flies of flattened shape with the head comparatively small, sometimes partly sunken in the thorax. The feelers, which have apparently but a single segment, are hidden in cavities near the mouth. The legs are short and strong with broad, flat thighs; the short, wide feet have large claws. Wings when present have a neuration akin to that of the Muscaria; in some genera (as *Melophagus*—the well-known "Sheep-tick"—(fig. 165) they are wanting. These insects live parasitically on mammals and birds; the Horse "Forest-fly" (*Hippobosca equina*) (fig. 148) is a typical example of the family.

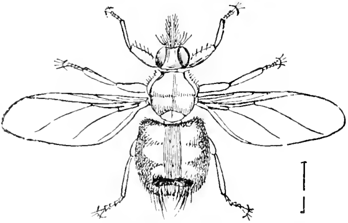

FIG. 148.—Horse "Forest-fly" (*Hippobosca equina*, Linn.), Europe. Magnified 3 times. From Osborn (after Packard), Bull. 5 (n.s.), Div. Ent. U.S. Dept. Agr.

Braulidæ.—The *Braulidæ* or "Bee-lice" are minute wingless insects allied to the Hippoboscidæ, but distinguished by the short sucker, the second maxillæ being clearly paired, as well as by the absence of both simple and compound eyes. The feelers, sunk in cavities of the head, are clearly three-segmented with a feathered bristle. The thorax is broad, and there is no scutellum. Wings and balancers are alike absent. The legs are short, with thick thighs, bent shins, and five-segmented feet; the terminal foot-segment is very broad and bears instead of claws, comb-like rows of spines. The family comprises but a single genus (*Braula*) which lives parastically on Bees.

Nycteribiidæ.—The *Nycteribiidæ* or BAT-PARASITES are the most

degraded of the Diptera. The small head is turned upwards and backwards into a cavity on the thorax, which is round or oval and bears on either side a comb-shaped organ, probably a vestigial wing, and a minute balancer. The legs are long with flattened shins and five-segmented clawed feet. The few known species live as parasites on bats.

ORDER 15.—HYMENOPTERA.

Structure.—The SAW-FLIES, GALL-FLIES, ICHNEUMON and other parasitic flies, ANTS, WASPS and BEES, which are included in this Order, are characterised by their two pairs of membranous wings with comparatively few nervures and cells, well-developed mandibles, and very highly specialised body-structure. Their most remarkable feature, perhaps, is the partial or entire fusion of the first abdominal segment (*propodeum*) (fig. 18 *n*) with the thorax; the "waist" which is so marked a feature in many Hymenoptera comes therefore not between thorax and hind-body but behind the first abdominal segment. The dorsal region of the prothorax is much reduced but the pronotum (fig. 18 *d*) is largely developed at the sides and even towards the lower aspect of the body, the prosternal sclerites (fig. 18 *a*, *b*) being correspondingly reduced, and in some cases quite hidden. The mesothorax (fig. 18 *e*, *f*, *g*, *h*, *i*, *j*, *k*) forms the greater part of the fore-body; at the base of each wing is a small plate—the *tegula* (fig. 18 *t*). As the apparent thorax contains, as mentioned above, an abdominal segment, it is sometimes known as the "alitrunk." The six legs are always well-developed, and the feet are usually five-segmented; in some families each trochanter has two segments. The wings are usually rather narrow, and the fore-wing is always longer and broader than the hind-wing; the costa of the latter is, in most cases provided with a row of curved hooks which fasten on to a fold in the dorsum of the fore-wing.

Thus the two wings of each side are united so as to present a single firm surface during flight. There may be five longitudinal nervures (sub-costal, cubital, and three anals) and these together with the cross-nervules divide the wing into a moderate number of cells. A tinted area the *stigma* is usually to be seen towards the end of the costa; below this is the radial cell, beneath this several cubital cells, and beneath these again several discals. The hind-body has ten evident segments in the Sawflies, in other families seven or eight, and in one four or five only are recognisable. The tergite of each segment overlaps the sternite. Throughout the order an ovipositor or a sting is well-developed in the females. The head is very easily movable on the fore-body; the feelers are usually simple or clubbed, sometimes angled (made up of scape and flagellum). Mandibles are always present, but the form of the first maxillæ varies greatly in the different families. Those of Sawflies are not very unlike those of beetles, but in the Bees they are modified into elaborate, kneading, brushing and sucking organs (see pp. 77-8).

Life-history and Habits.—The Hymenoptera pass through a complete metamorphosis. The larva is in all cases eruciform, but varies from a caterpillar with numerous prolegs (among the Sawflies) to a legless maggot (among the Ichneumons, Wasps, Ants and Bees). The larval head is always developed, so that the maggot never assumes the very degraded form characteristic of the higher Diptera. The pupa is free, the various organs of the imago being easily recognisable in all cases, and is enclosed in a cocoon spun by the larva, or sealed up in a cell by its parent or nurse. Many instances of virgin reproduction occur among the Hymenoptera. The higher families show the greatest care for the young and the highest

development of social life to be found among invertebrate animals (see below, pp. 331-7). The Ants, and some of the Wasps and Bees live in large communities, the majority of the members consisting of undeveloped females known as "workers" or "soldiers," who build the nest, provide food for the larvæ, defend the colony, and manage its affairs.

Classification.—The division of the Hymenoptera into Terebrantia and Aculeata according as the female possesses an ovipositor or a sting cannot be maintained. The sting is only a highly modified ovipositor, poison glands are present in all the families, and several large Ichneumon flies, classed in the terebrant (ovipositor-bearing) division, can inflict a painful sting. The Hymenoptera are now divided into two sub-orders distinguished by the relation between the thorax and the hind-body (3).

Sub-Order A. Sessiliventres.

The **Sessiliventres** are those Hymenoptera in which the first abdominal segment is incompletely fused with the thorax, and is not followed by a marked constriction or "waist," the lateral outline of the body being continuous. The anal lobe of the hind-wing is large and the trochanter of each leg is divided into two segments. The females have an ovipositor adapted for boring or cutting. The larvæ often have, in addition to the six thoracic legs, many pairs of prolegs on the hind-body; they feed on the tissues of plants (157). The Sessiliventres may be divided into three families.

Cephidæ.—The *Cephidæ* or Stem-sawflies are small, slender insects distinguished by a free and elongate pronotum—a primitive character not found in any other of the Hymenoptera. The first abdominal segment has its tergite interrupted centrally by a small triangular membrane whose apex is in front. The front shin has a single spine. The ovipositor of the female is composed of two saw-edged processes by means of which holes are bored into the stems of plants where the eggs

are laid. The saw is protected by two flaps which are conspicuous at the tail-end of the body. The larva which feeds within the stem is a white, fleshy grub (fig. 149 *a*, *b*, *c*) with mere vestiges of thoracic legs. Only 100 species of this family are known; they are distributed over Europe, North Africa and North America, and occur in Japan. *Cephus pygmaeus* (fig 149 *e*) is well-known as injurious to wheat.

Siricidæ.—The *Siricidæ* are fairly large insects, usually brightly coloured. The front lobe of the mesoscutum is not separated by the lateral lobes from the mesoscutellum. The pronotum though large dorsally is not free from the rest of the thorax. The first abdominal tergite is divided centrally by a small oblong membrane. The hind-body is long and cylindrical, ending in a very prominent spine in the female. She is provided with a very perfect boring ovipositor enabling her to lay eggs in the wood of trees, wherein the large white fleshy grub with mere vestiges of thoracic legs and a stout tail-spine lives and feeds. Only about 100 species of Siricidæ are known; they are characteristic of the northern forest regions.

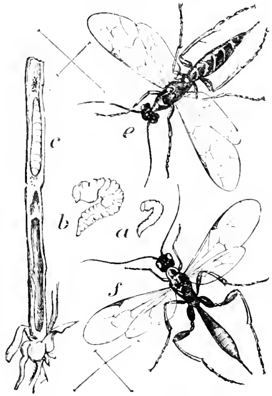

FIG. 149.—*e*. Corn Saw-fly (*Cephus pygmæus*, Curt.), Europe. Female, magnified 3 times; *a*. outline of larva, natural size; *b*. larva, magnified; *c*. larva in stem, natural size; *f*. Ichneumon fly (*Pachymerus calcitrator*), whose grub feeds on the larva of the Cephus, magnified. From Riley (after Curtis), Insect Life, vol. 2 (U.S. Dept. Agr.).

Tenthredinidæ. — The *Tenthredinidæ* or SAWFLIES are distinguished from the preceding families by the side lobes of the mesoscutum (fig. 18 *ff*) separating the central lobe (*e*) from the mesoscutellum (*g*). The pronotum is relatively small and closely fused with the mesothorax. The Sawflies are mostly insects of moderate size. The feelers are very variable; the number of segments is usually nine, but there may be as few as three or as many as forty; usually they are thread-like, but sometimes feathered. The fore-shin bears two spines. The hind-body of the female is provided with an ovipositor consisting of thin paired plates with the inner edge toothed to act as a saw and the outer face roughened to serve as a file; these saws are protected by a pair of sheaths. By means of them the female makes cuts in

plant-tissues and lays her eggs there. The larvæ are caterpillars with six well-developed thoracic legs and many, sometimes sixteen, prolegs on the hind-body (fig. 150). Most of them feed openly on leaves, but in some genera they are concealed and protected within swellings or galls which arise in the tissues of the food-plant. The pupæ are enclosed in cocoons which are often buried in the ground. About 2000 species of Sawflies are known; the family is widely distributed, but is much more numerous in North America, Europe and northern Asia than in tropical or southern countries.

Sub-Order B. Petiolata.

In the **Petiolata** which comprise the vast majority of the Hymenoptera the first abdominal segment is intimately connected with the thorax, and the second segment (sometimes also the third) is very narrow in diameter forming a marked "waist" or "stalk" between the (apparent) fore- and hind-bodies. In cases where this waist is short as well as narrow, the hind-body seems to be

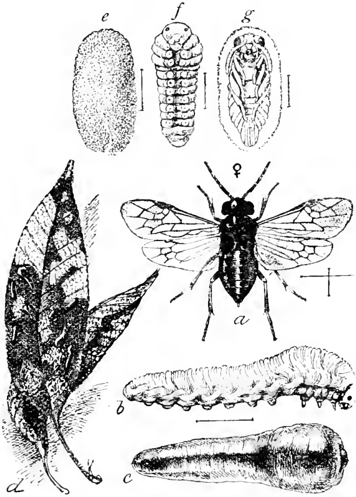

Fig. 150.—*a.* Pear Saw-fly, *Eriocampoides limacina* (Retz.), Europe. *b.* larva without and *c.* with its slimy coat; *e.* cocoon; *f.* larva before pupation; *g.* pupa, magnified 4 times; *d.* leaves with larvæ, Natural size. From Marlatt, Circ. 26 (2nd ser.), Div. Ent. U.S. Dept. Agr.

sessile. The joint between the first and second abdominal segments is very complex and allows great mobility, so that the hind-body with its ovipositor or sting can be readily turned in any required direction. The larvæ of all the Petiolata are white, legless maggots, provided in some way with food by their parents.

Cynipidæ.—The *Cynipidæ* or GALL-FLIES are very small Hymenoptera usually black or dark in colour. The feelers with twelve to fifteen segments are thread-like and straight. The pronotum is small dorsally, but embraces the mesonotum on either side as far back as the base of the forewing; the mesonotum has a large convex scutellum which partly covers the metanotum and propodeum. The wings have no stigma and only two or three longitudinal nervures and a single cubital cell. The trochanters are two-segmented. The abdomen is very complex in structure; the third and fourth tergites are large and convex, and overlap those behind them to a great extent. The slender ovipositor of the female with toothed tips to its borers can be withdrawn into the abdomen and partly coiled. The majority of the larvæ of the Cynipidæ live in galls on plants, due to the irritation set up by the act of egg-laying, or by their own presence in the plant-tissues (see below, pp. 303-4); the gall of each species is of characteristic form—the "oak-apple" is a well-known example. But some Cynipid larvæ live as inquilines or "cuckoo-parasites" in the galls due to the activity of other species. Others again are parasitic on the larvæ of other insects. The Cynipidæ are universally distributed (157).

Evaniidæ.—The *Evaniidæ* are a small family of Hymenoptera distinguished by the insertion of the second abdominal segment ("stalk") of the hind-body on the dorsal aspect of the first (propodeum). The feelers are straight and thread-like, with thirteen or fourteen segments. The wings have few nervures and the trochanters of the legs are two-segmented. The larvæ live parasitically on other insects; the females of the genus *Evania* lay their eggs in the egg-cases of Cockroaches (3).

Ichneumonidæ.—The *Ichneumonidæ* or ICHNEUMON-FLIES are an exceedingly large family. The feelers are long, straight and many-jointed, tapering towards the tip; three ocelli are always present on the crown. The wings have for the Hymenoptera a complex neuration; a distinguishing character is the presence of two cells between the cubitals and the second posterior cell (at the anal angle of the fore-wing) (fig. 149 *f*). Rarely wings are quite absent. The stalk of the elongate hind-body is attached to the lower or hinder aspect of the first abdominal segment, which is very large, while the metathorax is relatively short, so that the middle and hind pairs of legs are inserted

close together. The trochanters have two segments. The females are provided with ovipositors which in some cases are several times as long as the body; by means of these they lay their eggs in the bodies of caterpillars. The forms with exceptionally long ovipositors, such as *Rhyssa* (fig. 151), prey upon wood-boring grubs; this species lays her eggs in the burrows of Sirex on whose grubs her larvæ feed as external parasites; in most cases, however, the ichneumon maggots feed internally on the juices of their victims. Over 6000 species of Ichneumonidæ are already known, and the family is distributed in all parts of the world (**158, 159**).

Braconidæ.—The *Braconidæ* are a large family, closely allied to the Ichneumonidæ, but distinguished by having only a single cell on the fore-wing between the cubitals and the second posterior cell. The

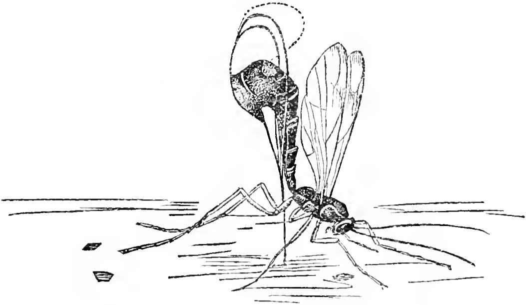

FIG. 151.—*Rhyssa persuasoria* (Linn.), Europe, female ovipositing. From Riley, Insect Life, vol. 1 (U.S. Dept. Agr.).

larvæ live like those of the Ichneumons, and the range of the family is equally wide (**158 b**).

Chalcididæ.—The *Chalcididæ* are a very large family of small Hymenoptera distinguished from all the preceding families of Petiolata by their elbowed feelers, which have from seven to thirteen segments. The pronotum is partially free and does not reach back to the insertion of the fore-wings. The neuration is very simple; a single thick nervure runs from the base of the wing to the costa, giving off at its termination a very short branch. The trochanters are divided. The Chalcididæ are frequently of brilliant metallic colours; over 4000 species have already been described and they occur in all parts of the world. The eggs are laid in galls, or in nests of the higher Hymenoptera so that the larva may feed on the

contained maggot. Some species attack the caterpillars of moths, and others like *Chalcis ovata* (fig. 152) feed in pupæ.

Proctotrypidæ.—The *Proctotrypidæ* are a large family of small Hymenoptera distinguished from the Chalcididæ by the pronotum being closely fused with the mesothorax and reaching back to the bases of the fore-wings. The neuration varies greatly; in some genera a few nervures and cells are present; in others none. The hind-body is pointed at the tip and the ovipositor is tubular. The

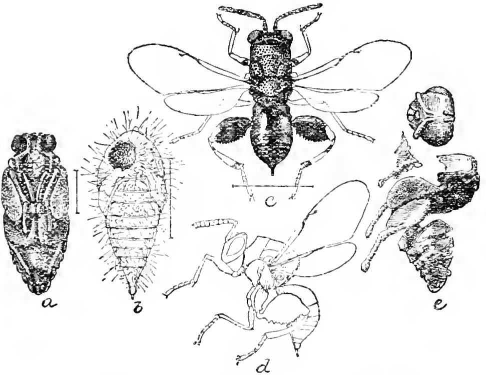

FIG. 152.—*c*. *Chalcis ovata*, Say., N. America; *d*. outline from side; *a*. pupa; *e*. cast pupal skin, magnified 4 times; *b*. pupa of Moth (*Orgyia*), whence chalcid has emerged, twice natural size. From Howard, Bull. 5 (tech. ser.), Div. Ent. U.S. Dept. Agr.

trochanters are usually segmented, but in some genera they are simple. The larvæ live parasitcally within the bodies of insects; those of some very minute species find food enough in other insects' eggs. In some Proctotrypidæ the larva in its first stage is broad in front and tapers behind to a point whence spring several tail-processes; this is ultimately changed into the ordinary Hymenopterous maggot. Some genera of the sub-family *Mymarinæ* — tiny and delicate insects, with narrow wings fringed with long hairs—are aquatic in their habits and their larvæ are believed to feed in the eggs of dragon-flies. The Proctotrypidæ have a world-wide range and must number many thousands of species (160).

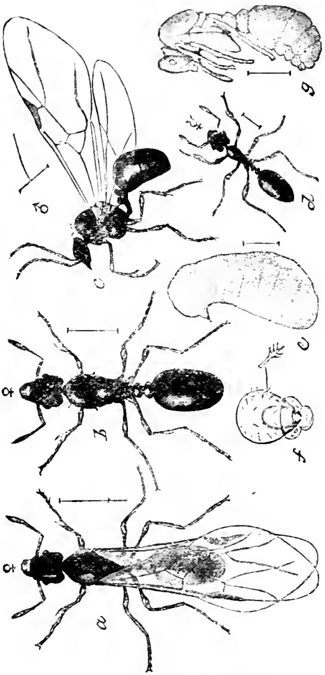

FIG. 153.—Ant, *Tetramorium cæspitum* (Linn.), Europe. *a*. Female; *b*. female after loss of wings; *c*. male; *d*. "worker"; *e*. larva; *g*. pupa, magnified 4 times; *f*. head of larva, more highly magnified. From Marlatt, Bull. 4 (n.s.), Div. Ent. U.S. Dept. Agr.

In all the following families of Hymenoptera the trochanters are undivided.

Chrysididæ.—The *Chrysididæ* are a comparatively small family of Hymenoptera distinguished by the brilliant blue, green, or crimson metallic hues of their exceedingly hard and firm exoskeleton. The hind-body has only three to five visible segments. The thirteen-segmented feelers are elbowed. The females lay their eggs in the nests of bees and wasps, where the chrysid larvæ live as cuckoo-parasites, devouring the food stored for the bee or wasp-grubs. Several hundred species are known and the family is generally distributed.

Formicidæ.—The *Formicidæ* or ANTS are a large and highly important family of Hymenoptera. They are characterised by the great constriction of the "stalk" or second abdominal segment at its front and hind edges, so that it assumes a swollen or nodular form centrally; in many genera the third abdominal segment forms part of the "stalk" and is similarly nodular. The fourth segment is

often exceedingly large, hiding to a great extent the three succeeding segments which can be observed. The first segment of the feelers is short and stout, the second long; these two form the scape, and the remaining (eight to eleven) segments attached at a marked angle to these, make up the flagellum. Ants live in large communities, consisting of many males and females and immense numbers of wingless, undeveloped females or "workers." The workers build the nests, and collect food which consists largely of honey; this can be disgorged by them to feed the larvæ and their comrades remaining in the nest (fig. 153; see also below pp. 335-6). Ants are exceedingly numerous in tropical countries, but become much scarcer in species in cooler regions; they are however distributed throughout the world (**161-5**).

Mutillidæ.—The *Mutillidæ* are a comparatively small family sometimes known as "Solitary Ants." They resemble the Formicidæ in the deep constriction between the second and third abdominal segments. They do not live in communities and there are no "workers"; the males are winged and the females wingless. In the male the pronotum reaches backwards on either side to the base of the fore-wing, and the last visible abdominal segment has one or more spines or blunt teeth. The females have stout digging legs with spiny shins. In both sexes the haunches of the middle pair are close together. The Mutillidæ are mostly black and red or yellow in colour; many species are adorned with bands of white hairs. Their larvæ live as parasites in bees' nests. The family is fairly abundant in the tropics of both hemispheres, but becomes scarce in cooler regions; only two species inhabit our islands (**162**).

Thynnidæ.—The *Thynnidæ* are a small family agreeing with the Mutillidæ in the sex-distinction—the winged males and wingless females—but distinguished by the absence of a constriction between the second and third abdominal segments. The male pronotum reaches back to the forewing-bases as in the Mutillidæ and there is often a spine on the last abdominal tergite. The range of this family is like that of the last, but only a single species (*Methoca ichneumonoides*) reaches England (**162**).

Scoliidæ.—The *Scoliidæ* are a large family of Digging-Wasps which resemble the Mutillidæ in the constricted stalk of the hind-body, but are distinguished by the widely separated middle haunches; both sexes, moreover, are winged. The feelers of the male are long and threadlike, those of the female shorter and curved. The sides of the pronotum reach back to the bases of the fore-wings; the first abdominal segment is as long as, or shorter than the mesonotum. The legs are short and stout, usually clothed with stiff hairs and spines. The fore-wing has always a radial and at least two cubital cells, but the apical third of the wing is often without any neuration. The hind-body, especially in the female, is very long and heavy; in the male it is more slender and the last segment bears one or more spines. The Scoliids vary in size; some are giants among the

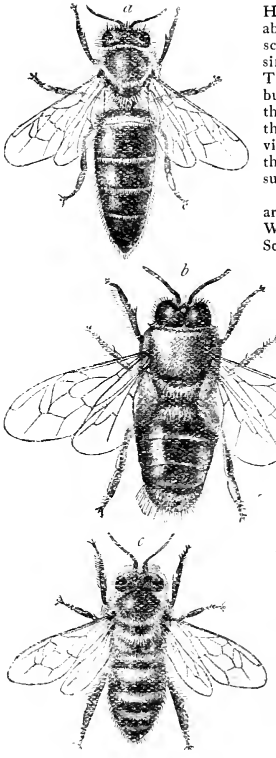

FIG. 154. — Honey-Bee (*Apis mellifica*, Linn.). *a*. Female (queen); *b*. male (drone); *c*. unfertile female (worker). Twice natural size. From Benton, Bull. 1 (n.s.), Div. Ent. U.S. Dept. Agr.

Hymenoptera. They are abundant in the tropics, but scarce in cooler regions; only a single species inhabits England. The females dig in search of burrowing beetle-larvæ which they paralyse by their sting; they then lay an egg on the victim's body, thus providing the maggot on hatching with a supply of food (**162**).

Pompilidæ.—The *Pompilidæ* are a large family of Digging-Wasps, differing from the Scoliidæ in having no constriction between the second and third abdominal segments, but agreeing with the three preceding families in the backward extension of the pronotum to the forewing-bases. The legs are relatively much longer than in the Scoliidæ, and the whole aspect is more slender and wasp-like. The fore-wing has a radial and two or three cubital cells; the neuration covers the whole wing-area. The wasps of this family construct nests, usually by digging in sandy banks, and capture spiders (more rarely insects) which they paralyse by stinging, to furnish food for their grubs. The Pompilids, like the Scoliids, vary greatly in size; they are distributed in all parts of the world (**161-5**).

Sphegidæ.—The *Sphegidæ* form the largest family of the Digging-Wasps; they are dis-

tinguished by the short pronotum which does not reach back to the forewing-bases. In structural details the genera of the family show great variation. These insects make nests in the ground or in wood, and capture insects of various orders which serve as food for their larvæ; they are abundant in all parts of the world (**194**).

Vespidæ.—The *Vespidæ* or true Wasps are distinguished by the longitudinal folding of their wings when at rest—a character not found among the ants or digging-wasps. The feelers have always thirteen segments in the male and twelve in the female; the eyes are kidney-shaped and the tongue is concave or bifid at its tip. The pronotum reaches back on either side of the mesothorax to the base of the fore-wing. In the sub-family *Eumeninæ* (Solitary Wasps) the tongue is elongate, longer than the mandibles though these are often very long and grooved; the middle shin has one spine at the tip, and the claws of the feet are toothed; the species usually make earthen nests and capture and store caterpillars and other insects as food for their larvæ; the females being all fully developed there are no "workers," and no true social communities, though individuals of many species form colonies by building their cells close together. Among the *Vespinæ* (Social Wasps) the tongue is shorter, the mandibles are never very long or grooved, the middle shin has two spines at the tip, and the foot-claws are simple; undeveloped females or "workers" are found among nearly all the species, which live in true social communities making nests by their united labour out of paper which they work up from vegetable tissues, hunting for insects and gathering fragments of fruit wherewith they feed their larvæ. The Vespidæ are distributed throughout the world, but the species are much more numerous in the tropics than in cooler regions (**161-5**).

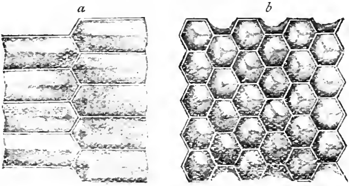

Fig. 155.—Waxen cells of Honey-bee. *a.* in section; *b.* in elevation. Natural size. From Benton, Bull. 1 (n.s.), Div. Ent. U.S. Dept. Agr.

Apidæ.—The *Apidæ* or Bees may be known from all other families of Hymenoptera by being clothed with feathered hairs and by having the basal segment of the hind foot flat and broad—in many cases as broad as the shin. Except in a few genera which, like the Wasps, have the tongue concave at the tip, that organ is pointed; in the higher bees such as the Humble-bees and Hive-bee it is very long and serves as an elaborate sucking-organ (see pp. 18-19, fig. 15). In the details of their form and habits the Bees show great diversity;

most of the genera are "solitary," that is they form no true social communities, though the proximity of the nests of many pairs often leads to large assemblies. The nests are formed in the earth, hollowed out in wood, or constructed of hardened clay; the usual food of bees and their larvæ is honey. Some genera are "unbidden guests" in the nests of others, and the larvæ of some live as actual parasites on those of other bees. The higher bees form true social communities consisting for the most part of undeveloped females or "workers" (fig. 154). The cells of their nests are made of wax (fig. 155) which is secreted by their abdominal glands; they collect pollen from flowers in the cavities of their wide flattened hind-shins, and suck honey by means of their grooved tongues. The Apidæ are world-wide in their range (**161-5**).

Chapter V

INSECTS AND THEIR SURROUNDINGS

> Ye insects small, to which one leaf
> Within its narrow sides
> A vast extended world displays
> And spacious realms provides.—SKELTON.

Abundance of Insect-Life. — Hitherto we have considered Insects mainly with regard to the form and structure of their parts, and the process of growth by which these parts have been developed. In discussing the uses of the various organs it has been necessary to touch upon the relations of the individual insect with the outside world. With a general knowledge of the structure, life-history, and classification of insects, we can now pursue this subject more fully, and study some of the chief points of correspondence between living insects and their surroundings.[1]

A fact early forced on the attention of the observer of living insects is their abundance. If in our countries we cannot make acquaintance with the hordes of ants and swarms of locusts described by travellers in the tropics, we are soon led to see that, both in the number of individuals and of kinds, insects exceed all other animals. This fact can be brought home by the zoological exploration of an ordinary dwelling-house. A number of animals

[1] This special study of living animals in relation to their surroundings is distinguished by naturalists as "bionomics."

will be discovered that obtain shelter and food by making themselves the "unbidden guests" of man. Among these the House-Mouse, possibly also the Brown Rat, alone represent the Vertebrates, while one or two kinds of slugs are the only members of the great Molluscan branch. Among Arthropods we may find three or four species of spiders, but when the insects are examined it will be seen that almost each one of the larger orders has several representatives which get their living in various ways. The Cockroach, which we took as our type of insect structure, abounds in the kitchen; by its power of omnivorous feeding, and its rapid reproduction, it has, in most town-houses at least, driven out the less unpleasant House-Cricket, which also belongs to the order Orthoptera. A Springtail, a Bristletail, and a Book-louse, find food and lodging among neglected piles of paper, being very possibly associated with one or two small Beetles. Several beetles will be found too burrowing in old woodwork, or devouring skins (fig. 156), and the housewife will be fortunate if her stores of food are entirely free from other insects of the same order. Unless preventive means are freely used three or four kinds of small Moth will be noticed flying about unused rooms, while their caterpillars busily devour cloth and fur. Flies of several distinct families are to be seen inside any window-pane, and, though the larger portion of these may have come in from outside, several kinds have been bred within the houses, their maggots having fed in cheese, or in corks, or in refuse matter which, in some neglected corner, has escaped the housemaid's broom. The animal inhabitants of a house, then, confirm the estimate of naturalists that Insects outnumber in their species all the rest of the animal world together.

The same impression is conveyed by the study of animal life out of doors. With the exception of birds, insects are the only animals, which in this country force themselves on our attention. In a wood-clearing on a summer's day the swarms of Flies, Gnats and Midges, will not let the most unobservant passer-by forget their presence ; as

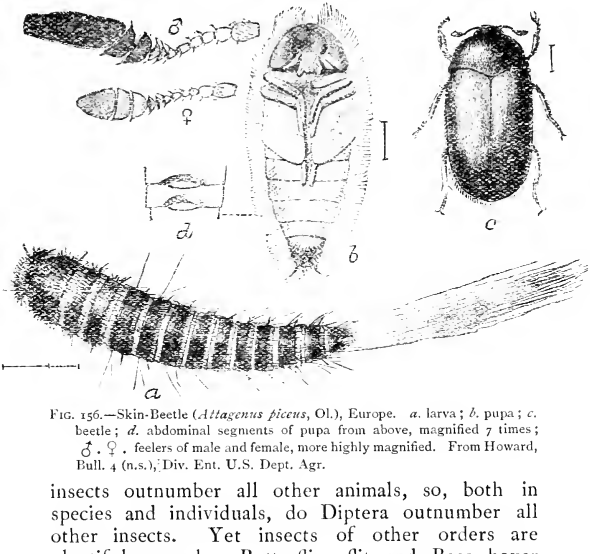

FIG. 156.—Skin-Beetle (*Attagenus piceus*, Ol.), Europe. *a.* larva ; *b.* pupa ; *c.* beetle ; *d.* abdominal segments of pupa from above, magnified 7 times ; ♂ . ♀ . feelers of male and female, more highly magnified. From Howard, Bull. 4 (n.s.), Div. Ent. U.S. Dept. Agr.

insects outnumber all other animals, so, both in species and individuals, do Diptera outnumber all other insects. Yet insects of other orders are plentiful enough ; Butterflies flit and Bees hover around the flowers ; Dragon-flies dart across the clearing in pursuit of prey ; Grasshoppers leap among the herbage. Shaking the branch of a

tree we can bring down a shower of Beetles, Caterpillars and Plant-bugs. And search in more concealed situations will reveal yet other insects. Underground, grubs are devouring the plant roots, while pupæ lie in their cells awaiting their final change. Beneath stones lurk Ground-beetles, which as soon as night falls will sally out in pursuit of prey. Under the bark or within the wood of many trees are burrowing the grubs of Beetles, while the caterpillars of tiny Moths eat out their winding tunnels within the tissues of the leaves.

Insects then have achieved a remarkable degree of success in the "struggle for existence." This is due largely to their perfect locomotion, and especially to their power of flight. In structure they have reached the highest point possible to the arthropodous type. The specialised head with its beautiful sense-organs; the reduction of the legs to three pairs, giving rapidity and certainty to the motions of the body, and affording in the double tripod the best mechanical base of support; the presence of wings, and the moderate abdomen never too bulky for easy carriage,—all contribute to place Insects pre-eminently above other arthropods. The blood and air-systems of insects, too, favour a life of abundant energy, the blood directly bathing all the tissues and receiving fresh oxygen at once in all parts of the body through the remotely branching air-tubes. The diversity of ways in which insects are able to feed has also largely contributed to their success in life; and by the very general adoption of metamorphosis the same individual often comes to feed in different ways in the successive stages of its life-history, an obviously economical arrangement for the species, since the drain on each of the various food-supplies is lessened.

Moreover the adoption of metamorphosis by storing up food during larval life, and so largely obviating the necessity for feeding in the perfect stage, enables the imago to devote full attention to the breeding function and largely to increase the output of eggs. Metamorphosis too increases the proportion of young which will survive out of those hatched, since the conditions of larval life are in most cases easy, and the food-supply abundant. This is notably the case among such insects as the Ants and Bees which provide a nest to shelter the grubs, and expend their energies in procuring food for them.

Insects creatures of the Land and the Air.—The branching air-tubes of Insects, and the almost universal presence of wings among them, mark them out as essentially creatures of the air and the land. The air and, as we have seen, every possible location on the land, is thronged with them. But it is to the air that they belong primarily, since special adaptations for life on the ground, or in concealed situations on plants, such as under bark, appear to be secondary. Of all the larger orders the Beetles show to the greatest extent a tendency to give up the air for the ground; and among them can be traced stages in the complete degeneration of the wings. In all Beetles only the hind-wings are used for flying, the fore-wings being modified to form the hardened "wing-cases" or elytra (fig. 157). Within the same family of ground-

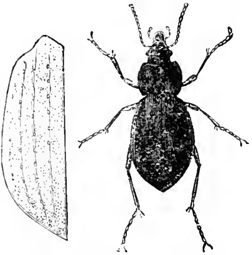

FIG. 157.—Ground-beetle (*Carabus*). Natural size, the left forewing or elytron to the left, magnified.

beetles may be found some species which have the hind-wings fully developed and capable of flight; others with these wings so reduced that they can be covered by the wing-cases without any folding; others again in which the wings have almost disappeared, though the wing-covers can be raised; and, lastly, others in which the two wing-cases are firmly joined together by their inner edges so as to form a single hard plate, organs originally wings thus being transformed into an armoured covering for an insect which has taken entirely to a terrestrial life. The loss of wings by the female of the Common Cockroach was dwelt upon in the opening chapter (p. 29).

Cave-Insects.—Flying through the air, then, or taking advantage of any resting or feeding place on the earth and the plants which grow thereon, insects have established themselves wherever animal life can exist at all. And besides spreading themselves over the earth's surface some insects have penetrated into its depths. The caves which, especially in limestone districts, extend in narrow galleries and vast halls for miles underground are tenanted by many species of insects belonging to several orders. Seven kinds of Springtails are known to inhabit the cavern of Mitchelstown in the south of Ireland, while dozens of species of Springtails, Crickets and Beetles, have been described from some of the caves of Carniola in southern Austria and Kentucky in North America (167, 168). Some of these are evidently recent immigrants into the underground world, being identical with species commonly found in ordinary surroundings above-ground. Others, however, are true cave-insects, evidently descended from ancestors which strayed or were carried into the caves at some distant period. They have now become specially modified in the course of generations in correspondence with

their underground home. The most striking characters of cave-insects are their pale colour and their blindness. The development of pigment in the skin of insects is known to be largely due to the action of light; in the total darkness of the caves, therefore, little or no pigment is developed, and the inhabitants—both insects and other animals—tend to assume a bleached appearance. As regards the blindness of cave-insects it has been found that, in the most typical cave-beetles, not only is there no trace of a cornea on the outer skin of the head, but the optic tracts of the brain have entirely disappeared also. Many naturalists see in this atrophy of the eyes a direct result of the life of many generations in total darkness, the absence of light—the stimulus to which eyes and their associated nerve-centres respond—is supposed to have led to the withering of the organs by disuse (**167**). This view, however, implies belief in the transmission from generation to generation of characters acquired during the life-time of the individual. On this account many students hesitate to ascribe the blindness of cave-insects to the direct effects of darkness and disuse, and prefer to regard it as resulting from "cessation of selection" (**57 a**). Those organs of animals, which are in constant use, are believed to be kept up to the mark by the rigid action of natural selection; for example, an insect living above ground with defective eyesight would quickly perish. But should a race of insects become transferred to a totally dark cave, individuals with good sight would cease to have any advantage over those with defective eyes; natural selection would cease so far as eyes were concerned, and these organs, it is believed, would degenerate and finally disappear. The weakness of this theory lies in the unlikelihood that mere cessation of selection could so overcome the

hereditary tendency for eyes to be developed as to lead to the total loss of those organs. Accordingly another factor has been invoked—that of "economy of nutrition." There is a general tendency among cave-animals to decrease in size, and their food-supply is undoubtedly very limited. Hence to get rid of any useless organ might be of considerable benefit since the food-material necessary for its support would be available for the nourishment of useful parts.

As a compensation for the loss of sight the senses of smell and touch seem to be more highly developed in cave-insects than in their relations of the upper world. The feelers, which are the special seat of these senses, are relatively longer in cave-species than in above-ground members of the same genus. This is markedly seen in the Bristletail, *Campodea* (fig. 65), while the length of the feelers in a species of springtail (*Entomobrya cavernarum*) found in several caves in Kentucky increases as the depth of the cave increases (167).

Springtails form the majority of the insect-population of caves. The underground conditions carry to an extreme the darkness and concealment of the usual dwelling-places of these insects—beneath stones and in damp earth. The cave-springtails pass through their bodies the red earth which carpets the floor of the underground galleries, and get food therefrom in shape of vegetable refuse—fragments of plants carried in by the subterranean streams or of fungi which grow on the cave walls. Nourished on such meagre fare the Springtails themselves form the food of the Beetles of prey which share their gloomy dwelling-place.

Fresh-water Insects.—We have seen that Insects are essentially creatures of the air and the land; yet

a considerable number pass the whole or the greater part of their lives in the waters of rivers, lakes, and ponds. Among insects which are aquatic in all stages of their existence we can distinguish between those which glide or skate over the surface of the water, diving not at all or only exceptionally, and those which habitually dive and swim through the water after the manner of fishes. The most typical of the surface-dwellers are the bugs (Hemiptera) known as "pond-skaters," and their allies—the family Hydrometridæ. They are long, narrow insects; the legs of the front pair, comparatively short, serve to seize prey or anchor to a support; while the greatly lengthened middle and hind-legs, by strong rapid strokes, carry the insect quickly over the surface of the water. If pond-skaters be watched resting on a shallow brook in the sunlight it will be seen that a bright circle surrounds the shadow cast by each foot. These circles indicate refraction of the light-rays due to the depression of the surface film at the points where the feet rest on it; the film sinks in under the feet but is not broken, its resistance being enough to support the insect's weight. No bright margin surrounds the shadow cast by the body which is thereby shown not to rest on the surface. Pond-skaters are entirely covered with a thick, velvet-like pile; the hairs are so close together that the surface-film cannot penetrate between them. Consequently when the insect dives an air-bubble forms around it, providing a store of free oxygen for breathing, and preventing any access of water to the spiracles (**170**).

Among the Coleoptera the Whirligig Beetles (Gyrinidæ) frequent the surface of ponds and brooks where they may be seen in small companies, performing a whirling, mazy dance over the surface-film. These insects, when they dive, carry down with

them a small air-bubble; the film which encloses this stretches from the tip of the wing-covers to the hinder end of the abdomen. They are not, like the pond-skaters, completely enveloped in air while under water.

The Beetles of a nearly-related family (Dyticidæ) belong to the group of insects which live habitually submerged. Their elongate shape and their smooth rounded contours are admirably adapted for motion

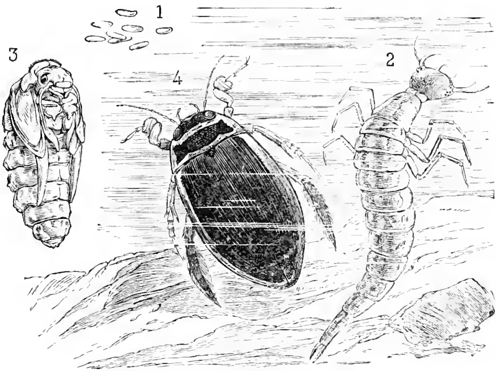

FIG. 158.—Water-Beetle (*Dyticus marginalis*, L.), with its eggs (1), larva (2), and pupa (3). Natural size.

through the water, but there is no dense hairy covering as in the pond-skaters to ensure the formation of an air-bubble; the breathing of the Dyticids while under water is provided for in quite another way. The abdominal spiracles open on the upper surface of the segments, which are completely covered by the wing-cases when the wings are shut. The wing-cases being convex and the upper surface of

the abdomen depressed, a considerable amount of air is enclosed, allowing the insect to remain submerged for some time. Though these beetles spend the greater part of their time in water, they are able to fly, and so make excursions from one pond or stream to another (**170**).

Another mode of adaptation to life in the water is shown by the family of bugs known as "water-scorpions" (Nepidæ). They are provided with a pair of long-grooved appendages at the tail-end of the body; these can be closely pressed together and interlocked by means of short hairs so as to form a tube, the tip of which pierces the surface-film when necessary and conveys a supply of air to the spiracles situated at the hinder end of the abdomen. These insects, like the allied "water-boatmen" (Notonectidæ), have well-developed wings, and make excursions by night to find a new watery dwelling-place (**170**).

Many insects lead an aquatic life only during their larval stage, the imago being adapted for life in the air. Naturally enough, however, such insects are to be found flying chiefly in the neighbourhood of the water whence they came and in which they will lay their eggs—the Mayflies and Midges for example. The contrast between the conditions of the larval and the imaginal life in such cases is most striking, and can only have been brought about by slow degrees. A certain amount of moisture in the earth is necessary to the well-being of many burrowing larvæ, while some are found in semi-liquid mud, in decaying refuse, or in animal excrement. In such surroundings breathing through the lateral spiracles becomes impossible, and we find that access to the air-tubes takes place only by one or two pairs of spiracles near the head or tail-end of the body, sometimes opening through "respiratory trumpets" whose

expanded mouths can be thrust out of the clogging surroundings of the mud or refuse into the fresh air, while the grub remains concealed and continues to feed. A similar suppression of most of the spiracles, with the development of a tubular process at the tail-end of the body in connection with the tracheal system, is the adaptation by which many aquatic larvæ breathe

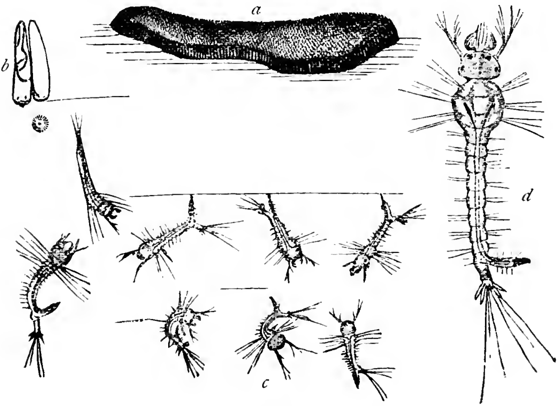

FIG. 159.—*a*. Floating egg-mass of Gnat; *b*. two eggs, magnified, with newly-hatched larvæ below; *c*. larvæ hanging from the surface film, diving, and rising, magnified; *d*. larva, highly magnified. From Howard, Bull. 4 (n.s.), Div. Ent. U.S.A. Dept. Agr.

—for example, the grub of the Gnat (figs. 72, 159) and the "rat-tailed maggot" of the Drone-fly. The families of insects nearly related to these have larvæ which live in mud and damp earth, and this suggests that it was from the shores that the waters were invaded by these insect-hosts.

But there is another division of aquatic larvæ still

more perfectly adapted to life in the water. The grub

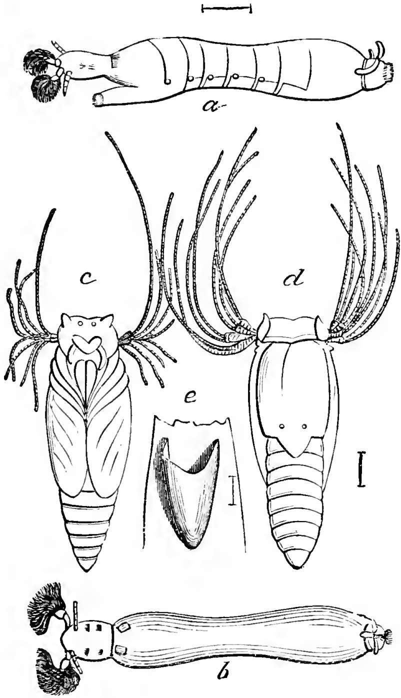

FIG. 160.—*a*. Larva of *Simulium ornatum*, Mg., from side; *b*. from below; *c*. pupa, from front; *d*. from behind, magnified 7 times; *e*. pupa case, magnified 4 times. From Osborn (after Verdat), Bull. 5 (n.s.), Div. Ent. U.S. Dept. Agr.

of the Gnat or the Drone-fly needs to rise to the sur-

face at intervals and pierce the film with its air-tube in order to get a fresh supply of oxygen. But the pupa of the Sand-midge with its tubular gill-filaments (fig. 160 *c*, *d*), or the larva of a Mayfly with its tracheal gill-plates, can remain in the water throughout its life, drawing, as do the fishes, sufficient oxygen from the dissolved air. It is interesting to notice that within the limits of a single and restricted Order—the Dragon-flies—we find some larvæ breathing by means of tracheal gill-plates, and others taking supplies of water into the hind-gut over whose walls run branching air-tubes; while in the final nymph stage the thoracic spiracles are open, and the insect, raising the front part of its body above the surface, breathes through them after the manner of an imago (170). These various adaptations to an aquatic life within a single group indicate clearly that the habit of living in water is not primitive among insects, but that it has become acquired by different races at different times in the course of development. It may be presumed that larvæ with the more perfect adaptations for breathing when submerged—leaf-like or thread-like gills—are older inhabitants of the water than those which have to rise periodically to the surface to take in a supply of air.

Marine Insects.—Insects have not only invaded rivers and lakes, they have established themselves to some extent at least, along the margin of the sea. On a sunny day by the shore, myriads of Flies can be seen hovering over the seaweed cast up by the tide. These have been developed from grubs which live and feed in the decaying weed, and are able to bear immersion twice daily. Around the rock-pools many Midges may be noticed. Their grubs feed on growing green seaweed, and spend their whole life in the salt water, breathing the dissolved

air, as do their fresh-water relations, by means of gill-filaments, or simply through the surface of the skin. Many species of Beetles inhabit the shore, and are submerged twice daily, when they lurk under stones or burrow into the sand; their hairy bodies are not easily wetted, and in one of the best known marine beetles (Aëpus) there are paired air-sacs in the hind-body which are believed to act as reservoirs for breathing while the tide is up. Several kinds of very small Springtails may be seen on the surface of rock-pools at low-tide; probably when the water rises they retire into crevices of the rocks. They are covered with a very fine, dense pile, and it seems impossible to wet them. The absence of wings is a common character among sea-shore insects. The beetles of the genus Aëpus are wingless and so is the small bug Aëpophilus often found in their company, as well as the female of the midge Clunio whose mate, though winged, appears not to fly but to use his wings as sails as he skims over the surface of the rock-pools. The tendency of insects on oceanic isles to lose their wings has often been noticed, and the loss of the power of flight explained as an advantage, since insects which do not fly cannot be blown out to sea. Possibly the absence of wings in so many sea-shore insects can be explained in like manner. Several genera of pond-skaters have one or two species which frequent the water of estuaries and harbours; these are in all cases wingless, though their fresh-water relations, are, as a rule, winged. The extreme of adaptation to marine life is shown by the bugs of the genus Halobates (fig. 154) (**171**)—also belonging to the family Hydrometridæ—with their short anchor-like fore-legs and their immensely long and slender middle and hind-legs, the middle shin and foot being

fringed with long hairs. The elongate wingless fore-body of these insects and the greatly reduced hind-body give them a most peculiar and characteristic appearance, and the dense pile wherewith they are clothed keeps them dry. They have been observed gliding over the calm seas of the tropics, often hundreds of miles from land, or clinging to drifting substances whence they could suck food. Their eggs have been picked up attached to the floating feather of a sea-bird.

Geographical Distribution.—Having seen in what diverse situations insects are to be found we turn next to consider their distribution over the earth's surface. The range of any insect is, of course, limited to some extent by its habits and its food supply. Mayflies cannot be expected to occur in the midst of a sandy waste, nor wood-boring Beetles in a region where there are no trees. But apart altogether from such limitations as these the distribution of species, genera, and families of insects, has much to teach the student. Some groups are almost world-wide in their range, others discontinuous, others confined to a single district; though there is nothing in their habits or feeding to call for such restriction. Within our own islands we can find instances of these various types of distribution. A vast number of species are found everywhere that the conditions render their presence possible. Some—like the great Water-beetle *Hydrophilus piceus* and the Purple Emperor Butterfly *Apatura iris*—are never, or very rarely, to be seen northward of the Trent or westward of the Severn. Others, on the contrary, such as the burnet moth *Zygæna minos* and the boring-beetle *Mesites Tardyi*, are entirely absent from the south-eastern districts of Great Britain while they abound in certain western and highland regions and in Ireland. Com-

parison of such facts as these suggests to us the fortunes of the various species in the battle of life. The widespread forms must be dominant and vigorous, while those with a confined or discontinuous range in the hill-country and the west must be the older members of the fauna, driven out of the eastern plain which they once held. The insects with a south-eastern distribution represent, on the other hand, the newest immigrants into our islands which have not been able to force their way far to the north and west.

Such distributional facts as our own islands furnish on a small scale can be studied on a grand scale in the world at large. Some vigorous and dominant species—such as the "Painted Lady" Butterfly *Pyrameis cardui*—are to be found in all quarters of the globe, while a vast number of insect-families are cosmopolitan; the Nymphalidæ, for instance, to which this butterfly belongs, swarm in the tropics and are represented at the far north of Greenland. Many groups of insects, such as the Papilionidæ among butterflies and the Cicindelidæ among beetles, are most abundant in tropical countries and are found to decrease in numbers and importance as the observer journeys north or south from the equator. Others, however, as the Sawflies (Tenthredinidæ) and the Rove-beetles (Staphylinidæ) are specially characteristic of the great northern or Holarctic Region, dying out towards the south.

It is interesting to find that the regions into which the earth's surface has been divided, by students of vertebrate zoology (**172, 173**), serve fairly well to indicate the distribution of insects. The following seven regions are perhaps the most satisfactory in the present state of our knowledge:—

1. Holarctic: including Europe, North Africa, North and Central Asia, Canada and the Northern United States.
2. Oriental: including India, Southern China, the Indo-Malayan district (eastward to Celebes).
3. Ethiopian: including Africa south of the Sahara.
4. Mascarene: Madagascar and neighbouring islands.
5. Australian: Papua, Australia, New Zealand, and Pacific Islands.
6. Neotropical: including South and Central America, and the West Indies.
7. Sonoran: including the greater part of the United States with Northern Mexico.

Many groups are confined to one or other of the Zoological Regions, three sub-families of Nymphalid butterflies—the Heliconiinæ, the Brassolinæ and the Ithomiinæ being peculiar to the Neotropical; such have probably been developed and specialised within the Region and have never occurred elsewhere. An immense number of genera are confined to each of the various regions, the Neotropical being the richest in peculiar forms, and the Oriental next. As most insects have the power of flight and often travel great distances, a certain amount of overlapping between the faunas of two neighbouring regions is to be expected. Several typically Ethiopian forms range northwards into Syria, while a species of the characteristic tropical Nymphaline genus, *Charaxes* inhabits the shores of the Mediterranean. Over a large tract in North America, insects of the Holarctic fauna common in the Old World intermingle with Sonoran forms altogether peculiar to the New. Many typically Oriental genera spread eastward through Papua to New Caledonia and Northern Australia.

Insect-groups afford many examples of discontinuous distribution. Moths of the family Uraniidæ occur in the Neotropical, eastern Ethiopian, Mascarene, Oriental and Australian regions; it is specially noteworthy that the two genera which inhabit respectively

tropical America including the West Indies, and Madagascar, are very nearly related to each other. Former land-connections bridging the existing oceans are often invoked to explain such distributional facts as these, but it is more likely that the insects are the scattered remnants of groups once world-wide in their range. Closely allied genera of Dragon-flies inhabit Chili and New Zealand, but the remains of a member of the same group in the Jurassic rocks of Europe show that, in all probability, these insects of the far south represent the last survivors of an ancient race which ages ago migrated from a northern home (**175**).

Vegetable-Feeders.—The surroundings of any animal naturally depend largely on the sources whence it draws its food. The various means by which Insects get their living have been often incidentally referred to in previous pages. As might be expected in a class so dominant and widely distributed, all methods of feeding prevalent among animals are practised by insects. A vast number depend directly on plants for their food; every kind of plant and every part of a plant is laid under contribution. The caterpillars of Moths and Sawflies (fig. 150), many Beetles and their grubs, for example, feed openly on leaves which they bite up with their powerful mandibles and devour. Plant-bugs and Aphids get their food-supply also from leaves, by piercing the tissues, and thence sucking the sap. Other smaller insects, as the caterpillars of many tiny Moths and the maggots of certain Flies, find not food only in a leaf, but shelter also, burrowing between the skin of the upper and lower surfaces and eating up the soft central tissue. Some of these leaf-miners form narrow winding tunnels, others spread their depredations over a wide area of the leaf and give rise to dry, brown blisters. While the foliage leaves are thus eaten by

a host of insects, others find food in the parts of flowers. Many small Caterpillars and Beetles feed entirely on petals, while honey forms the staple food of Bees, and Moths, and very many Flies.

Insects and Flowers.—In their visits to flowers for the purpose of gathering honey, Insects do a service to the plants by transferring pollen from the stamens of one flower to the stigma of another and so ensuring cross-fertilisation. The honey has been regarded in the light of a payment made to the insects for this service—while it is believed by many botanists that the bright colours of flowers have been developed in order to attract insect-visitors. The high modification of the jaws in Moths and Bees, enabling them to suck honey from the deeply-placed nectaries of flowers, has been described in Chapter I; as also the "pollen baskets" on the hind shins of Bees. While some flowers can be fertilised by the agency of insects of various kinds, others are dependent on the visits of special sorts of bees or moths (176, 177). A most remarkable instance of the inter-dependence of plants and insects is afforded by the relations between the American Yuccas and the small white-winged moths of the genus Pronuba. The female in these moths, has,

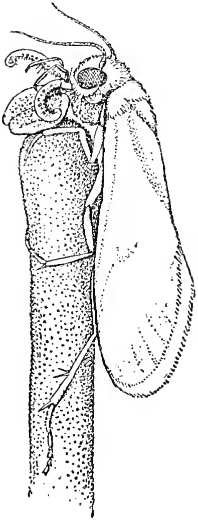

FIG. 161.—Yucca Moth (*Pronuba*), gathering pollen. Magnified 5 times. From Riley, Insect Life, vol. 4.

not only the palps of the first maxillæ developed, but the region of the maxillæ (palpiger) whence they spring produced into a pair of long flexible hairy processes (fig. 162 *b*). By means of these she collects (fig. 161) from the anthers pollen, which she deliberately carries to the stigma to ensure fertilisation. With her piercing ovipositor (fig. 162 *j*) —a most abnormal development among moths—she bores through the tissue of the pistil and by means of the flexible egg-tube, protrusible beyond the ovipositor, lays her egg close to the ovules of the Yucca. The caterpillar when hatched feeds on the growing seed of the plant, which would never develop were it not for the action of the Pronuba moth. This action is most wonderful, in that the moth herself gets no benefit from it. Her food canal is degenerate, and her jaws, useless for sucking, are devoted altogether to the gathering of the pollen; she does not feed in the perfect state. Doubtless her ancestors did so and were first attracted to the Yucca in search of honey, though the act of pollination is now performed only for the sake of the offspring (**178 a**).

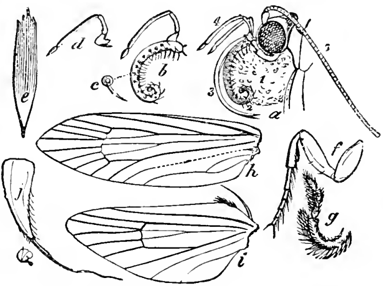

FIG. 162.—Yucca Moth (*Pronuba*). *a.* Head of female, the pollen ball (1) is held by the palpigers (2) of the 1st maxillæ whose galeæ (3) and palps (4) are shown; *b.* palpiger and palp, highly magnified; *c.* spine of palpiger, still more enlarged; *d.* palp separated; *f.* front leg; *g.* palp of 2nd maxilla; *h.* neuration of forewing; *i.* of hindwing; *j.* tip of abdomen with ovipositor. From Riley, Insect Life, vol. 4, U.S. Dept. Agr.

Root-Feeders.—While some insects thus gain livelihood for themselves or their young from flowers in the upper air, others burrowing underground devour the roots of plants. Many beetles which feed on leaves have grubs which feed on roots, different parts of the plant being thus laid under contribution by the insect during the different stages of its life-history. While some grubs, as those of the Chafers (fig. 119) and the Click-beetles, go down to the deeply-branching roots, others, as the maggots of various Flies, eat into the main root just below the surface. Large succulent roots are often riddled by the borings of grubs and this method of feeding is practised even by certain caterpillars which, leaving the usual open leaf-feeding habit of their relations, find shelter as well as food in the tissues of a large tap-root.

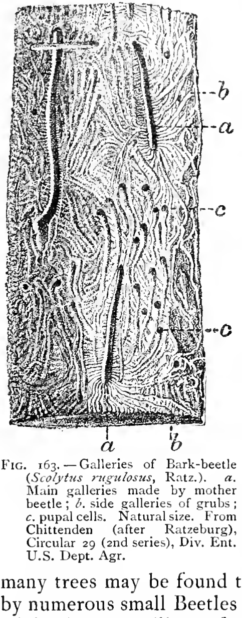

FIG. 163.—Galleries of Bark-beetle (*Scolytus rugulosus*, Ratz.). *a.* Main galleries made by mother beetle; *b.* side galleries of grubs; *c.* pupal cells. Natural size. From Chittenden (after Ratzeburg), Circular 29 (2nd series), Div. Ent. U.S. Dept. Agr.

Stem-Borers.—The stems of plants also afford shelter and food to insects. Just beneath the bark of many trees may be found the branching tunnels made by numerous small Beetles and their grubs (fig. 163); while the caterpillars of some Moths, and Sawflies, and the larvæ of Longhorn-beetles, make their larger galleries through the heart of the wood. These in-

sects eat away the wood with their strong mandibles and pass the fragments through their food-canals as they bore their way onwards. Like many of the root-feeders the wood-boring grubs are, as a rule, long-lived; the well-known caterpillar of the "goat" moth takes over three years to reach its full size. In most cases the wood-boring habit is confined to the larval stage, the perfect insect living in the open air. The female Moth lays her eggs on the bark, leaving the grub when hatched to bore its own way into the wood; but the Sawfly pierces the stem with her ovipositor so as to place the egg where the new-born larva will find itself amid congenial surroundings.

Galls.—The vegetable-feeding insects, whose habits we have briefly surveyed, necessarily mutilate the plants on which they live, riddling the leaves, eating away the roots, or tunnelling through the wood. Some insects, however, have the power of modifying the growth of the plant which is to afford them food. Around the spot where the female insect has laid her egg an excrescence or *gall* is formed, within which the grub shelters and feeds, the main mass of the plant remaining unaffected. The production of galls therefore seems calculated to supply the wants of the insect with as little damage as possible to the plant. Galls are of the most various shapes, smooth and spherical, like fruits: the well-known oak-apple for example, flat and round like buttons, or spreading out in leaf-like rosettes. One or more chambers may be found within each gall, containing the growing grub. The precise cause of the formation of galls has long been a subject of discussion among naturalists. Galls are known to be due to the activity of the meristem-cells of the plant under some stimulus, which has been variously ascribed to the mechanical irritation caused by egg-laying or to chemical irritation from a fluid

injected by the female insect with the egg (**179**). It is now generally believed, however, that the newly-hatched grub, or possibly the advanced embryo itself, sets up the irritation which leads to the formation of the gall. Galls are specially characteristic of a family of Hymenoptera, the Gall-flies (Cynipidæ); and a family of Diptera, the Gall-midges (Cecidomyidæ). But they are also produced by other insects, such as certain Sawflies, some Scale-insects, and a few Beetles. All parts of plants—leaves, branches, roots—may be the seat of galls (**3, 180, 182**).

Fungus-Eaters.—While the higher (flowering) plants furnish most of the food for vegetable-eating insects, the cryptogams are not neglected. As stated above, seaweed is devoured by various insects of the shore, and a considerable number of small Beetles together with the grubs of many Flies and Midges find their sustenance in fungi. The caterpillars in several families of Moths feed on the lichens which hang in festoons from the branches of trees, or cover the surfaces of rocks.

Scavengers.—Not fresh, growing vegetable tissues only, but decaying vegetable matter is sought after by insects as food. Damp, rotten refuse is found to be inhabited by Beetles and their grubs as well as by the maggots of Flies, while decomposing, rotten stems and leaves—whose decay is often hastened by the attacks of the insects mentioned in the preceding pages—furnish nourishment to many species. The damp earth formed by the waste of plant tissues is the food of Springtails and other humble insects. From such substances we pass by a natural transition to waste animal matter on which multitudes of insects depend for their livelihood. Many Beetles and their grubs, and a host of Fly-maggots, live and feed in dung as well as in the dead bodies of animals. The eagerness

of the Blowfly to leave her eggs in flesh is too well-known, and so quickly do such insects multiply when the food-supply of their grubs is abundant, as to justify the oft-quoted saying that three flies can devour the carcase of a horse more quickly than can a lion. The Egyptian sacred beetle carefully prepares a ball of dung which may serve as a food-supply for her grubs; while the Burying-beetles, with similar intent, laboriously inter the bodies of small animals whereon they have laid their eggs.

Insects of Prey.—As among mammals and birds so among Insects; a large number live by preying on their weaker, vegetable-feeding relations. Plant-lice and Scale-insects, which often swarm over plants, sucking sap from stalks and leaves, are greedily devoured by Ladybird-beetles and their grubs (fig. 116) as well as by the grubs of Lacewing and Golden-eye flies. The latter are covered with tubercles and spines whereto adhere the dried-up skins of the plant-lice. Thus clothed with the remains of its victims the lacewing-grub creeps unobserved on its prey. The most typical of the carnivorous insects—the Tiger-beetles and the Dragon-flies for example—catch their prey by open chase, the beetles running it down, the dragon-flies pursuing it on the wing. Wherever the vegetable-feeders make their way they find themselves hunted by the flesh-eaters. The root-feeding grubs fall a prey to the grubs of the Ground-beetles, while the tunnels of the bark-borers are inhabited by various Rove and other beetles which, together with their grubs, devour the wood-eating larvæ. Nor do the carnivorous insects prey only on members of their own class. They often attack earthworms, slugs and snails; and many literally "fly at higher game." The Gadflies which pierce the skin of cattle and horses and suck their blood, the Breeze-flies and Mosquitoes

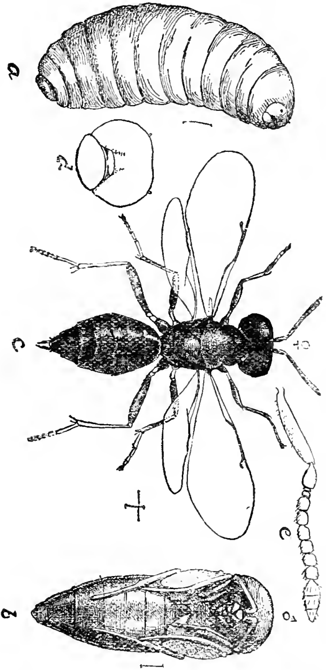

FIG. 164.—A Hyperparasite (*Dibrachys bouchcanus*, Ratz.), Europe. *a*. larva, magnified 8 times; *d*. its head, more highly magnified; *b*. pupa of male, magnified 10 times; *c*. female, magnified 12 times; *e*. feeler, magnified 36 times. From Howard, Bull. 5 (tech. ser.), Div. Ent. U.S. Dept. Agr.

which do the same to ourselves, must be regarded as predaceous insects rather than as parasites, since they boldly attack the creature whence they draw their food, and do not spend their whole lives in or on its body. Some Dragonfly nymphs are habitual cannibals, devouring the weaker members of their own species.

Many insects hunt to get a living for themselves, others to furnish their offspring with food. The Digging-wasps seize caterpillars or spiders; they paralyse or kill the victim by a sting sometimes in the neighbourhood of the ventral nerve-cords, and then carry it to their nest before laying their eggs that

their grubs when hatched may devo· . ne Social Wasps kill small insects, breaking ..em into pieces capable of being eaten by their grubs, which they feed throughout the course of their growth as birds feed their young.

Parasites. — The habits of the Ichneumon-flies and related Hymenopterous families introduce another means of livelihood. The female lays her eggs in the body of some insect—usually a caterpillar—piercing the skin with her ovipositor. The grubs, when hatched, feed within the body of their "host," avoiding the vital parts so that the caterpillar may remain alive and their food-supply not be cut off. Even the wood-boring grubs are not safe from the attacks of Ichneumons, many of which have ovipositors long and strong enough to pierce through the wood and reach the larva burrowing within. These Ichneumon-grubs, being devourers of living insects in or on whose bodies they pass the whole of their lives, are usually regarded as parasites, though their method of feeding is rather transitional between a normal carnivorous habit and true parasitism. Instances are known of the grubs of one species of

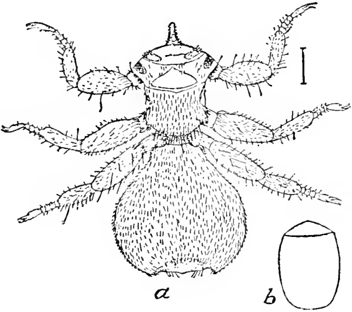

Fig. 165.—*a.* Sheep-tick, *Melophagus ovinus* (Linn.), magnified 7 times; *b.* puparium, magnified. From Osborn, Bull. 5 (n.s.), Div. Ent. U.S. Dept. Agr.

hymenopterous parasite being attacked by another—known as a secondary parasite or hyperparasite (fig. 164) which sometimes falls a victim in its turn to a tertiary parasite (183).

A considerable number of insects live in a truly parasitic manner in or on the bodies of vertebrates. Among external parasites some like the "sheep-tick" (fig. 165) pierce the skin of their host and suck blood; others, like the Biting-lice (fig. 166) eat hairs or feathers. These are parasitic throughout the whole of their lives, not through the larval stage only, and they show in their form the degradation which always accompanies parasitism. The wings of such insects have quite disappeared, while their organs of sense are always degenerate; many are blind. In correspondence with their habitation among the hairs of a mammal or the feathers of a bird, they usually have flattened bodies. In most cases—the insects mentioned above and the Bed-bug, which may be regarded as an "intermittent parasite," for instance — the body is flattened horizontally. But in other well-known intermittent parasites—the Fleas—the flattening is vertical, the body being compressed from side to side.

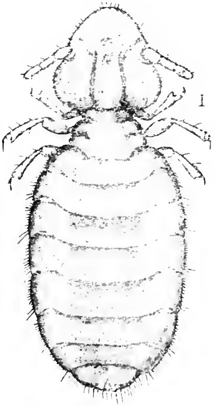

FIG. 166.—Cattle-louse (*Trichodectes scalaris*, Nitzsch), Europe. Magnified 35 times. From Osborn, Bull. 7, Div. Ent. U.S. Dept. Agr.

Other insects are parasitic on vertebrates during their larval stage only. The Bot-fly (fig. 167) for

instance lays her eggs on the hairs of a horse's body; through licking the part the horse takes these eggs into the mouth and swallows them. The grubs are hatched and feed on the lining of the stomach; being at length cast out with the dung, they bury themselves in the earth and pupate. These insects, and others with similar habits, like the Ichneumon-flies, show the

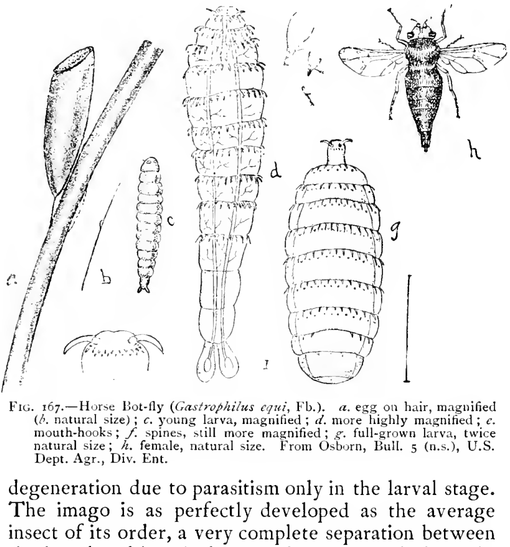

Fig. 167.—Horse Bot-fly (*Gastrophilus equi*, Fb.). *a.* egg on hair, magnified (*b.* natural size); *c.* young larva, magnified; *d.* more highly magnified; *e.* mouth-hooks; *f.* spines, still more magnified; *g.* full-grown larva, twice natural size; *h.* female, natural size. From Osborn, Bull. 5 (n.s.), U.S. Dept. Agr., Div. Ent.

degeneration due to parasitism only in the larval stage. The imago is as perfectly developed as the average insect of its order, a very complete separation between the larval and imaginal stages being strongly brought out in such cases. In the Stylopidæ (p. 224) the female who spends the whole of her life within the body of a Bee retains always her maggot-like form, while the

male becomes winged and leads an active life in the open air.

Inquilines.—A number of insects instead of actually devouring others, feed at their expense. Many Gall-flies do not themselves produce galls, but lay their eggs in the galls already formed by the activity of other members of their family. The nests of bees and wasps serve as a home for numbers of such "cuckoo-parasites." Some, like the grubs of the Oil-beetles, eat the stored-up honey; others, like the caterpillars of certain Pyralid moths, devour the comb; others again, like the maggots of Volucella, a genus of two-winged Flies, act as scavengers. Ants' nests are tenanted by many species of small Beetles, Aphids and Scale-insects, which do scavenging work for the ants or supply them with luxuries in the shape of sweet secretions. Hence they render service for the shelter and food provided by their hosts, and must be regarded as more honourable inquilines than those which take to their own or their offsprings' use the labours of others without making any return.

Abnormal Feeders.—It is of special interest to notice instances where insects abandon the method of feeding usual in their families to strike out fresh lines for themselves. It has just been mentioned that the grubs of certain Gall-flies live as inquilines in the galls of others. Within the same family are found insects which lay their eggs in the bodies of plant-lice or fly-maggots, their grubs living as parasites. The great family of the Ground-beetles (Carabidæ) are normally carnivorous, yet many of the species occasionally, and some habitually, take to a vegetable diet and devour roots. Caddis-worms are almost all plant-eaters, but the Hydropsychidæ devour insects and sometimes practise cannibalism. No insects are so typically vegetable-feeding as the

Lepidoptera, the perfect insects sucking honey and the caterpillars eating leaves or other parts of plants. The great Death's-head Moth (Acherontia), however, instead of gathering honey for itself from flowers, is known often to enter hives and rob bees, while the presence of small caterpillars feeding on the comb has already been mentioned. Butterflies sometimes forsake honey for such unsavoury food as blood from the wound of a mammal, or the juices of a putrefying carcase. Several instances are known of caterpillars which eat other insects. The larva of *Cosmia trapezina* feeds on oak and other leaves, but devours caterpillars smaller than itself which happen to get in its way; while other species are said to prefer insects to leaves whenever the opportunity arises; a small "looper" caterpillar has been observed to eat a larva three times as big as itself (**181**). A specially interesting carnivorous caterpillar is that of *Erastria scitula*, a south European Noctuid moth (fig. 168), whose female lays her eggs singly and far apart on trees infested with scale-insects. When hatched the young caterpillar selects a large female coccid, eats its way through the scale and devours the insect beneath. As it grows it makes a case for itself of the scales of its victims and its own excrement, bound together by silk which it spins. Protected by this covering, which closely resembles the bark of the tree, it roams about eating in its later stages several coccids every day (**178 b**).

Protection by foreign Objects.—The case-forming habit of the Erastria caterpillar introduces a fresh subject in the life of insects—the various ways in which protection from enemies, or shelter is secured. This caterpillar carries about its hard case wherever it goes. In correspondence with this habit its body is short and stumpy (fig. 168 *a*, *b*); three pairs of pro-

legs are developed whereof those on the fifth and sixth abdominal segments are used for walking, while the hindmost are fixed to the case to keep it in position. When fully grown the caterpillar chooses a crack in the bark or a fork between two branches, where it fixes its case, spins a cocoon and pupates, having first taken the precaution to gnaw an opening through which the moth can get out. This habit of gaining protection by making a case or shield of

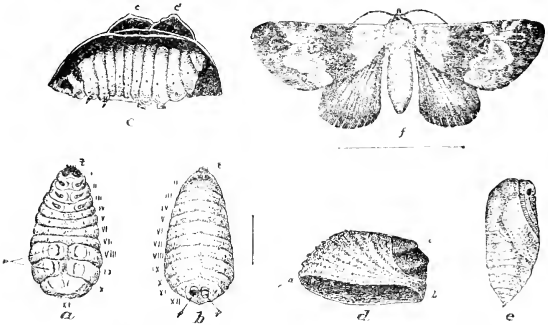

FIG. 168.—*f.* Moth (*Erastria scitula*, Ramb.), S. France. *a.* larva, under surface; *b.* upper view; *c.* case in section; *d.* case, outer view; *e.* pupa. Twice natural size. From Riley (after Rouzaud), Insect Life, vol. 6 (U.S. Dept. Agr.).

foreign objects is practised by many insects of different orders. The caterpillars of some clothes-moths (fig. 169) build up cylindrical cases out of fragments of the cloth on which they feed. The grubs of the peculiar flattened Leaf-beetles known as "tortoise-beetles" (Cassida) shelter themselves under their own excrement, which is discharged through the long anal tube standing vertically up from the hind-body, and collects to form a kind of flattened umbrella over the

insect's back. The larvæ of Midges (Chironomus) make tubes for themselves of the sand or mud at the bottom of the water wherein they live. The Caddis-worms or larvæ of the Trichoptera—another aquatic group—are all case-makers, forming their dwellings of small stones, leaves, twigs, fragments of rushes, or the shells of water-snails (**170**).

Protective Secretions.—While the caterpillar of *Erastria scitula* shelters itself beneath a case made of

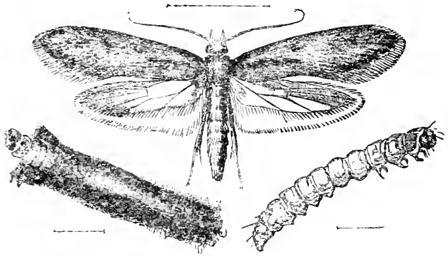

FIG. 169.—Clothes' Moth (*Tinea pellionella*, Linn.), with larva in and out of its case. Magnified. From Marlatt (after Riley), Bull. 4 (n.s.), Div. Ent. U.S. Dept. Agr.

foreign objects, the Scale-insects on which it preys carry protective coverings made entirely of a substance derived from their own bodies—a wax secreted by the glands of the skin. This wax is produced in fine threads which appear on the body of the newly hatched coccid, ultimately interlacing to form a firm shield or "scale" (fig. 170). The female insect settles down to a sedentary life beneath her waxy shelter, which at length completely covers her, becoming attached around its edge to the leaf or bark whereon she lives. Protective waxy coverings of a like nature to those of the coccids are to be

seen also on many Aphids. In the latter insects, however, the waxy dress retains its thread-like form as for instance in the "woolly aphid" or "American blight" of orchards. The young nymphs of a nearly allied

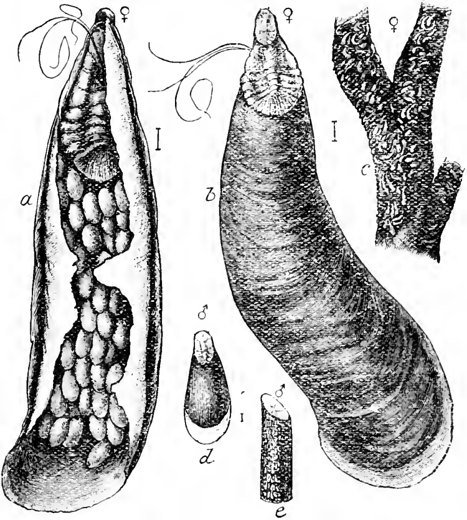

FIG. 170.—Scale-insect (*Mytilaspis pomorum*, Bouché). *a.* female, from beneath, showing eggs protected by "scale"; *b.* from above, magnified 24 times; *c.* female scales on branch, natural size; *d.* male scale, magnified 12 times; *e.* male scales on twigs, natural size. From Howard, Yearbook, U.S. Dept. Agr., 1894.

family of Homoptera — the Froghoppers — protect themselves by a frothy liquid — the well-known "cuckoo-spit" which entirely surrounds them as they lie sucking their food at the base of a leaf-stalk.

The caterpillars of some Sawflies (fig. 171) secrete a dark-coloured slime which envelopes and protects their bodies, giving them the appearance of a small black slug rather than of an insect larva.

Protection by Form.—The Froghopper-nymph in its frothy covering is soft-skinned and sluggish; defences, such as we have just been considering, are usually resorted to by insects which are weak and, in many cases, degenerate. Similarly grubs which feed in concealed situations—underground, within plant-tissues, or immersed in refuse—are soft-skinned and defenceless, their food-material providing them with shelter as well as with nourishment. But the Froghopper when fully developed, with a firm chitinised skin, two pairs of wings and powerful jumping legs, is able to live freely and openly on plants, needing no longer the shelter of the frothy "cuckoo-spit," since its activity enables it to escape from its enemies. In the same way the maggot which feeds underground in carrion becomes changed into a strongly-armoured fly or beetle, needing concealment and shelter no longer, but depending on its swift flight or its quick running for success in the battle of life. The protection afforded to active insects by every feature of their outward form—their hard skin, their spiny processes, their bristles and hairs, their perfect sense-organs and their powers of motion — is too obvious to need comment.

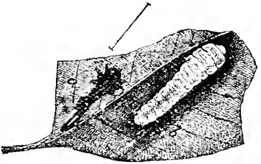
FIG. 171. — *b.* Grub of Sawfly (*Eriocampoides limacina*, Scop.), after casting dark slime-covered skin (*a.*).

Protective Resemblance.—But many Insects are protected in a special way by their form in conjunction

with their colour and appearance. Numerous species, spending their lives above ground, in open situations where they are subject to attack by hungry vertebrate and other enemies in search of food, harmonise in aspect so closely with their surroundings as to be concealed. For example, Moths, Grasshoppers, and Lantern-flies, habitually rest with hind-wings folded and concealed beneath the fore-wings. The hind-wings, invisible when the insect is at rest, are often brightly coloured—red, blue or yellow; the fore-wings on the other hand are usually mottled with various shades of brown or grey, and are quite inconspicuous as the insect sits on a rock or a tree-trunk. Such cases of *protective resemblance* are doubtless due to the action of natural selection, the individuals corresponding best with their surroundings having been preserved through many generations. In a previous chapter (p. 138) reference was made to the dark coloration of moths in cool and damp districts. It has been suggested that this is not due simply to the effect of cold or moisture in inducing the formation of dark pigment, but also to the selection of the darkest individuals through the surfaces where they habitually rest being necessarily darker than in a dry region. Studying the wing patterns of Butterflies we find that the front wings do not differ from the hind-wings; the upper surface of all four is usually brightly coloured. Butterflies, however, rest as a rule with the wings folded over the back so as to expose the lower surface to view, and this is usually protectively coloured with a mottled pattern of brown or grey. An observation made on a common African butterfly—*Hamanumida dædalus*—shows the importance of the nature of the wing markings in relation to the resting-attitude. In West Africa this insect rests with the wings folded over the back, exposing the tawny

under-surface, but in South Africa the wings are spread out, showing the brownish-grey upper side which harmonises with the colours of the rocks in that region (189). A well-known instance of perfect protective resemblance is afforded by the Indian leaf-butterfly (*Kallima inachis*). Its wings above are conspicuously adorned with purple and yellow, but beneath they are grey or brown, closely resembling a dead leaf. As the insect rests on a twig with wings folded over its back, the head and feelers are hidden beneath the fore-wings whose apex is produced into a point. From this a dark line like the mid-rib of a leaf runs across the wings, terminating at the pointed "tail" of the hind-wing which rests in contact with the twig, simulating a leaf-stalk. Likeness to leaves is to be noted in other insects. Among the Orthoptera the Tree-grasshoppers (Phasgonuridæ) often have their fore-wings of an oval shape, a green colour, and with the neuration closely resembling that of a leaf; while the "Leaf-insects" among the Phasmidæ not only have their wings like leaves but the segments of their legs flattened out to form leaf-like expansions.

Other Phasmids with their very long, thin and wingless bodies and slender legs are transformed into "walking-sticks." Likeness to twigs is also strikingly shown by the "looper" caterpillars of moths of the family Geometridæ. These caterpillars have lost all their abdominal pro-legs, except the two hindmost pairs. Clinging tightly to a branch with these they stretch out their slender bodies in a rigid attitude, the six thoracic legs being directed forward in close contact with the under surface of the thorax and so hidden from view (fig. 172). The resemblance to twigs is often increased by projections or tubercles on certain segments of the hind-body, while the colour is usually a shade of brown or grey, often with mottled

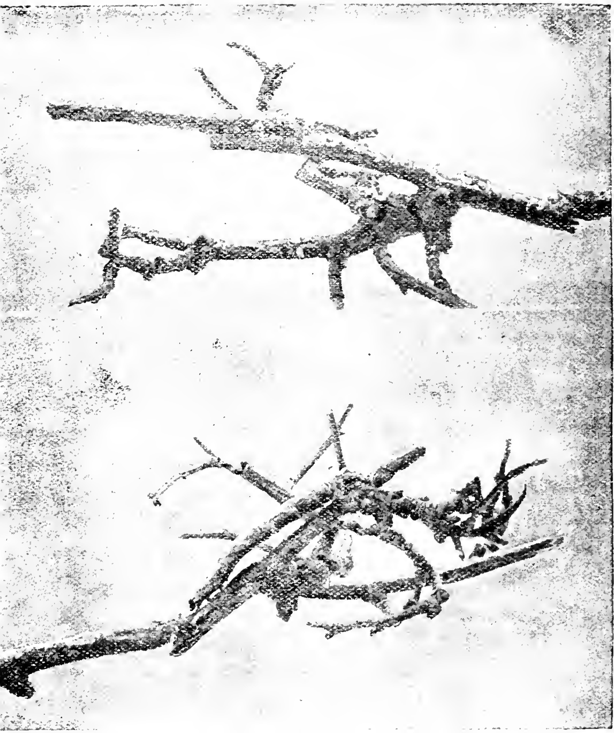

FIG. 172.—Caterpillar of Geometrid Moth (*Odontopera bidentata*), on a rose-branch; below, bent, as in walking; above, stretched out like a twig. From photograph by F. T. Eason, Irish Nat., vol. 2.

markings which recall the appearance of lichens. Most of these insects have the power of adapting their colour in response to their surroundings. The caterpillars of *Amphidasys betularia*, for instance, are brown when first hatched from the eggs; but those reared among green leaves and shoots turn green as growth proceeds, while when dark twigs are present with the food, a corresponding dark colour is induced in the caterpillars. The presence of light is necessary for the production of these colour changes, and the caterpillars are found to be no longer sensitive in their later stages. The dark pigment to which the brown or grey colours are due is deposited in the cells of the outer skin, while the green-colouring matter is found in the underlying fat; and experiments have shown that the presence or absence of both kinds of pigment is determined by the surrounding objects through the quality of the light reflected from them, the suppression of the superficial dark pigment allowing the deeper green to show through the skin and thus give its hue to the caterpillar. It has been shown that the formation of the dark pigment is hindered by the action of certain yellow rays of the solar spectrum, which are absorbed by dark objects, but reflected from green leaves and shoots. There can be no doubt that the power possessed by these caterpillars of modifying their appearance in accordance with their surroundings must be of great value in ensuring their preservation from enemies (184).

There are other insects which, without the exact resemblance to twigs shown by the loopers, are coloured and marked in such harmony with their surroundings as to be inconspicuous when at rest. The caterpillars of Hawk-moths for instance are by no means easily seen on their food-plants, the green surface of their bodies broken up by dark sloping lines agreeing well with the effect of light and

shadow among green foliage. Yet probably on account of their large size rendering them too conspicuous many of these caterpillars feed only at night, hiding by day on the ground. Several species which have adopted this habit are brown after the last moult instead of green, in correspondence with their resting-place; though the occurrence of an occasional full-grown green specimen shows that the habit has not been very long acquired. A vast number of caterpillars, however, belonging to various families feed always during the night. The value of protective resemblance is greatly lessened by movement, and it is therefore of advantage to these insects to be able to remain at rest throughout the hours of daylight (**83 a**).

Warning Colour.—But it is a matter of common observation that many insects are not coloured so as to be hidden, but rather so as to be as conspicuous as possible. The black and yellow banding of Wasps and many Bees, and the red, black-spotted Ladybird beetles; the red and black pattern of the Burnet and Cinnabar moths, and the yellow and black segmentation of the latter's caterpillar, are familiar examples of this fact among British insects, while abroad it is found that entire groups of Butterflies—the Heliconiinæ, the Danainæ and the Acræinæ—are marked by a glaring livery of some combination of brown, red or yellow with black or white, the pattern of the upper surface of the wings being substantially reproduced beneath, so that the insects are as conspicuous when at rest as when flying. Such bright colours are usually explained as of "warning" significance. They are believed to be associated with some noxious or hurtful quality whereof they act as an advertisement, insects possessing them being at once recognised as nasty or dangerous and therefore let alone by would-

be enemies. A single peck from a bird's beak, trying the edibility of a caterpillar, would prove fatal to the latter whether it were subsequently eaten or not; it is therefore decidedly to the insect's advantage to be quickly recognised as unpalatable and to be left untouched (184).

Among insects adorned with these warning colours wasps and bees are undoubtedly dangerous on account of their stings. The beetles, moths, butterflies, and caterpillars, are believed to be provided with noxious secretions which make them unpalatable to birds, lizards, and other insect-eating animals. Many experiments have been made with the object of testing the edibility of these insects, and it has often been found that birds which greedily devour insects with protective coloration as soon as they can detect them, refuse to touch those displaying warning colours. But evidence has been produced to show that this distaste for brightly-coloured insects is not universal; occasionally at least they are devoured despite their nature and appearance. On this account some naturalists have doubted whether warning colours really have the meaning usually ascribed to them (185). But no kind of protection can avail at all times and in all cases. The struggle for life among insect-eating animals must lead some to acquire the power of feeding on kinds which others cannot touch. And the fact that brilliantly-hued insects at times fall victims to hungry birds, lizards, or monkeys, cannot destroy the experimental evidence that bright colours are commonly associated with hurtful or nasty qualities.

Mimicry.—Strong testimony to the value of warning colours is afforded by the likeness which harmless insects sometimes bear to dangerous or noxious kinds. Clearwing moths (Sesiidæ) with their black and yellow banded bodies and wings almost destitute of scaly cover-

ing closely resemble wasps. Drone-flies (Eristalis) bear much resemblance to bees. Such likeness is known as "mimicry," and it is believed that the moths and flies secure immunity from attack through being mistaken for the stinging insects. In the same way tropical butterflies of the sub-families believed to be noxious—the Danainæ, Heliconiinæ, and Acræinæ—are "mimicked" by butterflies of other groups. In South America many species of Pieridæ are found whose wing-patterns, quite unlike those usually characteristic of their family, show staring contrasts of yellow, black, and red, in close imitation of various species of Heliconiinæ. A very common North American Danaine butterfly—*Anosia erippus*—whose wings are tawny brown with black veins and margins, is closely mimicked by a Nymphaline, *Limenitis misippus*, which belongs to the same genus as our graceful and delicately tinted "White Admiral." In some cases the female of a species is a "mimic" while the male retains the normal livery of his group. There are two Indian Nymphaline butterflies, *Hypolimnas bolina* and *H. misippus*, whose males are similar to each other, both having black wings with central white violet-tinted spots. The female of *H. bolina* has blackish wings with whitish marginal spots and is an imperfect mimic of the common Danaine butterfly, *Euplœa core*. The female of *H. misippus*, altogether unlike her mate, has tawny brown wings, the fore-wings with a white apical patch; she is an extremely perfect mimic of another common Danaine, *Limnas chrysippus*. Such strongly marked divergence between the two sexes of a species is surprising, but the varieties of *H. bolina* go far to bridge over the gap, the females showing the gradual growth of the tawny colour from a small basal spot to a large suffusion of the wing-area. It is hard to suggest what first led to the development of

the brown pigment, but, if protection by warning colours be a fact, it is easy to understand how the individuals in which it was most strongly developed were favoured in the struggle for existence. Among the South American Pieridæ which resemble Heliconiinæ a number of stages in the wing-pattern can be traced between the normal black and white or yellow species of the family and the perfect mimics (186).

Besides this mimicry of protected insects by harmless species, there is mimicry within the protected groups themselves. All Heliconiinæ have an easily recognised and characteristic aspect, and a large section of the Ithomiinæ in South America have assumed an aspect so similar that they were formerly classed in the same sub-family. Further, it is found that within this characteristically marked section certain species closely mimic other species of different genera. It is believed that a certain number of nauseous insects must fall victims to young insect-eating animals which have to learn by experience that "warning colour" and distastefulness go together. By reducing the number of "warning" patterns the education of the young birds and lizards to the advantage of the butterflies is made easy, a smaller proportion of insects being tried and rejected in a crippled or dying condition. And it is clearly of advantage to a rare protected species to resemble a common one, since the large majority of individuals of the two species which are sacrificed will necessarily be drawn from the former.

But considerable doubt has recently been thrown on the whole theory of mimicry, and attempts have been made to explain the facts just mentioned as the result of "accidental" causes or as the effect of similar surroundings on insects inhabiting the same districts (187, 188). The likeness which some insects bear to others from different geographical regions

cannot of course be regarded as mimicry, and may fairly be set down as "accidental." Where, as is almost always the case, the mimic occupies the same area as the species which it resembles, the theory of "similar conditions" is invoked to account for the likeness. But if this were the only cause, cases of mimicry should be very numerous, and should occur indefinitely among the various families and orders. Wasps and bees should be modified to look like moths, and at least some danaine butterflies should forsake the coloration usual in their family to assume the comparatively sober hues of nymphalines. Such cases are however quite unknown, and the fact that only those species and groups are mimicked, which are believed on good grounds to be protected, goes far to show that there is some advantage in mimicry to those insects which have adopted it.

Sexual Modifications.—Reference has already been made to various points of form and colour in which some male insects differ from their females. In almost all cases where an outward divergence between the sexes is to be observed, the male, though smaller, is more highly developed than the female. His sense organs are often more complex. Many male Moths and Beetles are provided with saw-like or comb-like feelers, while those of their females are simple. The eyes of many male Flies and Bees occupy a larger part of the head-area than do those of the females. The males of Cicads and many Locusts and Grasshoppers have highly developed sound-producing organs, which are absent or rudimentary in their mates. The tail forceps of male Earwigs are longer and more complex than those of the females, and a corresponding difference between the mandibles of the two sexes is to be seen in many Beetles and in some Lacewing-flies and Wasps. Spiny processes, sometimes of much com-

plexity, are developed on the pronotum of certain Chafers in the male only. In cases where one sex is without wings, it is almost always the female which has lost them, and degeneration in this sex has gone still farther in many insects. A female Psychid moth in outward form resembling a grub spends her life within the pupa-case, and the female Stylops—a legless and headless maggot—passes her whole existence within the body of a bee; while the winged males of both insects fly freely through the air. Among Butterflies and Dragonflies the wings of the male insect are often more brilliantly coloured than those of the female; many male Lycænidæ for example, as described in Chapter III (p. 132, etc.), have bright blue wings while their females are dark brown.

Various suggestions have been made as to the cause of these sexual differences. By some naturalists they are believed to be the direct result of the essential natures of the sexes. The small and active sperm-cell with a more abundant vitality than the passive egg-cell, dissipates energy while the egg-cell stores it up. So it is suggested that the male animal is, in his whole nature, more vigorous than the female. The acute senses, swift movements, and special adornments of form and colour found in male insects, are believed to be simply the necessary expression of masculine activity, while the wingless grub-like females of psychid moths and bee-parasites show feminine passivity in an extreme form (191).

The colours and ornaments of male animals are also explained as due to the selection through many generations by the females of the most attractive mates, those most richly and beautifully adorned thus transmitting their qualities to their offspring (190). Among some animals—birds and spiders for instance—in which a prolonged courtship and a display by the

male of his charms take place, there can be no doubt that this "sexual selection" has operated. But among insects no such selection on the part of the females has been shown to occur, except perhaps among grass-hoppers and other stridulating insects whose males charm the females by their shrill chirping (192).

On the other hand the suggestion has been made that the comparatively dull hues of female animals are due to the action of natural selection in preserving, through many generations, the least conspicuous or best protected individuals. It is believed that female insects are in greater danger from enemies than males; they necessarily take up exposed positions while laying eggs and are, as a rule, less active than the males in escaping from pursuit. Therefore a rigid selection has prevented the adornment of the female to anything like the same degree as her mate (88).

The facts mentioned above (p. 322), with regard to the Indian butterflies, *Hypolimnas bolina* and *H. misippus*, whose females are mimics of danaine species, while the males retain the usual coloration of their genus, give support to this last view. If, as is highly probable, mimicry be a result of natural selection, we see in these insects how that agency has acted on the appearance of the females only, for their protection, leaving the males unaffected. But in very many cases of striking sexual difference, it is evidently the male that has become modified while the female retains the primitive colour of her group. The Swift Moths (Hepialidæ) are a family characterised by brown or golden-coloured wings, but in the largest British species—*Hepialus humuli*—the male has pure white wings. The group of Ermine moths (Spilosoma and allied genera) are characterised by wings of a white or yellow ground colour; in the female of *Diaphora mendica* they are semi-transparent white, but in the

male smoky black. In both these instances the male is clearly the divergent sex, and it is of great interest to find that a primitive race of either species still exists; in the Shetland Isles the males of *Hepialus humuli* are yellow-brown, while in Ireland the males of *Diaphora mendica* are, almost without exception, white. These insular races doubtless represent the ancestral forms of the two species; it is hard to suggest what can have led to the striking modifications which their males have undergone over the greater part of their range.

Among the Lycænidæ already referred to, with their numerous species with blue males and brown females, it is probable that the male is the more highly modified sex, such a butterfly as *Polyommatus astrarche*, in which both sexes have brown wings, representing the ancestral type of the group. There is much reason for believing that dulness preceded brilliance in the evolution of insect colour. The partial blue suffusion over the wings of a female whose male's wings are entirely blue indicates that he has advanced farther in the development of colour than she. But whether the action of natural selection keeps down the tendency to adornment among the females, or the natural vivacity of the male necessarily expresses itself in brilliant colour, must for the present remain undecided. The fact that in Ireland and the Scottish Highlands the female of *P. icarus* is often almost as blue as the male shows that the causes of these divergences cannot lie entirely within the insects themselves.

The specially developed sense-organs of male insects are undoubtedly of use in helping them quickly to find mates and pair. The highly complex feelers of many male moths (fig. 7) give them a wonderful power of discovering the position of the females. A single captive female in a box will cause the "as-

sembling" of scores or hundreds of males eager to pay their court. It is often found that such complexity of antennal structure in the males is associated with vestigial mouth-organs, and consequently short imaginal life; the male must find a mate quickly if he is to pair at all. Some male Mayflies are provided with peculiar large frontal eyes, carried on columnar outgrowths of the head, in addition to normal lateral eyes like those of the females. The reduction of pigment and the presence of a thick layer of homogeneous fluid between the nuclear and rhabdom layers has led to the conclusion that the special function of these eyes is to discern moving objects in the dusk, to enable the male to secure a mate in the airy twilight dance of the short-lived Mayflies (193).

Family Life.—Among the vast majority of insects, family life exists only in a very rudimentary form. Pairing concluded, the female lays her eggs in such a situation as to ensure food-supply for the young, and maternal care as a rule goes no farther. The mother Mole-cricket, however, watches carefully over her eggs and feeds her brood until the first moult. Often the eggs are laid singly and the larva lives alone, or, if the eggs are laid together, the young scatter in search of food as soon as hatched. In other cases, however, there is an association among the members of a brood. Many young caterpillars unite to spin over their food-plant a web of silk (fig. 173) which affords shelter and protection to the whole family; usually, however, when a certain stage of growth has been reached, the limited food supply necessitates the dispersal of the family, whose surviving members pass the rest of their lives independently. Many adult insects of various orders habitually live together in flocks, but there is no mutual help among the in-

Fig. 173.—Colony of Young Caterpillars of Peacock Butterfly (*Vanessa io*) on Nettle. From photograph by R. Welch, Irish Nat., vol. 7.

dividuals. In the case of the migrating hordes of Locusts and Butterflies, however, the whole community moves in concert.

It has already been mentioned in this chapter (p. 306) that the Digging-wasps hunt for caterpillars or spiders which they carry to their nests, and seal up in a cell with an egg, thus working to provide food for their grubs in anticipation of hatching (**194**). It has been suggested (**195**) that this habit has been developed from that of the Ichneumon-fly who simply lays her egg in or on the living insect which is to form the food of her offspring. An intermediate stage would be presented by an insect which captured prey and then dug a hole wherein to bury it, laying her egg beside it. The habit of most digging-wasps—first preparing a hole and then hunting for food for the grubs—marks a further development. Progress in nest-making can be traced to a great extent among the various genera of Wasps and Bees; the primitive unicellular nest is improved into a linear arrangement of cells with a common opening, hollowed out either in the earth or in twigs, as may be observed among species of *Crabro*, *Colletes*, *Osmia*, etc. Another step in advance is furnished by the branched type of nest, in which the cells open off from the entrance or from a main passage; such nests are constructed by species of *Hoplopus*, *Halictus*, etc. Nests made out of various substances collected or secreted by the insects mark the highest stage in the building-habit. The leaf-cutter Bees (*Megachile*) nest in the earth, but within the earthen cell they form a beautiful lining made up of fragments of leaves, which they cut out with great accuracy by means of their mandibles. Mason-bees and certain slender wasps (*Pelopæus*) build, on the surface of rocks or walls, nests composed of particles of earth, sand, or lime, cemented together by the

spittle of the insects. Each nest contains a number of ovoid cells within which the grubs grow and feed.

All these insects show great care for their young, storing up food for their sustenance, and building nests for their protection. In most cases the food is stored, the egg laid and the cell sealed up, the mother never watching the growth of her offspring. But the digging-wasp Bembex leaves the cells open, and brings fresh supplies of flies to her grubs every day. Here then we have a family life comparable to that of birds. It often happens that a number of the "solitary" wasps or bees whose habits we have been considering form their nests close together, making an imperfect colony, or that a number of them pass the winter in company in some sheltered spot. But it is not apparently thus that the true social communities have been elaborated; these, like human states, have their origin in the family. For these communities three conditions are necessary—a nest large enough for a number of insects, a close grouping of the cells, and an association between mother and offspring in the perfect state. The last condition will be brought about by the emergence of the older insects of the brood while the mother is still occupied with the younger larvæ or their cells. In a single species of solitary bee (*Halictus quadristrigatus*) these conditions are almost fulfilled, but the first young insects to appear are males, and when the females are developed the mother dies (195).

Social Communities.—For the formation of a true community the mother must co-operate with her female offspring. A mother or queen among the Social Wasps (Vespidæ), after wintering, starts a fresh colony in the early spring. She builds her nest of paper which she makes from vegetable substances worked up with her mandibles, and moistened with her spittle.

The cells are regularly six-sided in shape, thus ensuring the greatest economy of space; the comb first formed by the queen consists of six or eight of these cells, supported on a central stalk. From eggs laid in them grubs are quickly hatched, and are fed by the mother on a mixed diet of honey and insects. When full-grown the larva is sealed up in its cell and becomes transformed into a pupa which soon changes into a young wasp.

These young insects are the small undeveloped females, or "workers," which form the vast majority in all insect communities. A division of labour is adopted, the queen devoting her attention chiefly or altogether to egg-laying, while the workers, whose ovaries are in a vestigial condition, build the nest and tend and feed the young. In wasp-colonies the workers enlarge the original comb by adding fresh cells around it, and then build successive storeys of cells supported by pillars, surrounding the whole with an outer wall of several layers of paper which assumes a pear-like shape, increasing in size through the summer with the growth of the community. A wasp's nest may ultimately hold several hundred inmates. Towards the end of the season fully developed females—"young queens"—and males—"drones"—are produced. These leave the nest and pair—usually with individuals from other nests; such of the young queens as survive the winter found fresh nests in the succeeding spring. Each wasp community only lasts from spring till autumn, and its dissolution may be hastened by the workers, who, expecting a cessation of the food-supply, cast out the undeveloped grubs from the nest on the approach of winter (163, 164).

The Humble-bees (*Bombus*) form colonies, lasting, like those of the wasps, only from spring till autumn; a queen, after wintering, herself starts the nest, the cells

being irregularly globular, composed of wax secreted by glands in the insect's abdomen (p. 70), and covered by a dome of leaves and moss. But the Hive-bees (*Apis*) and their allies, by their habit of storing honey and pollen as food for the winter, make permanent communities, not dependent on the changes of the

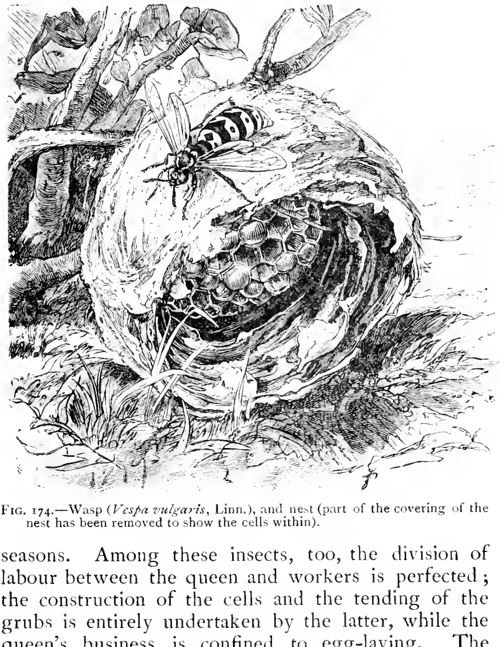

FIG. 174.—Wasp (*Vespa vulgaris*, Linn.), and nest (part of the covering of the nest has been removed to show the cells within).

seasons. Among these insects, too, the division of labour between the queen and workers is perfected; the construction of the cells and the tending of the grubs is entirely undertaken by the latter, while the queen's business is confined to egg-laying. The

waxen cells of the bees, forming the familiar honeycomb (fig. 175), are hollow, hexagonal prisms, set in two series back to back, divided by a partition. Some cells are devoted to the rearing of grubs, while others serve as store-houses for honey and pollen (fig. 176). Towards the outer margin of the comb are the large, irregularly shaped "queen cells," wherein the grubs

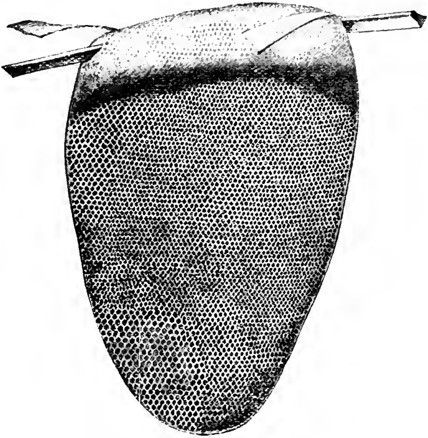

FIG. 175.—Comb of Indian Honey-bee (*Apis florea*, Fb.). ⅓ natural size. From Benton, Bull. 1 (n.s.), Div. Ent. U.S. Dept. Agr.

destined to develop into queens are fed on richer and more abundant food than falls to the share of those which will grow only into workers. The same grub will produce a female bee with developed or vestigial ovaries (see fig. 51) according to the food which it receives. The earliest food of all the grubs is a nutritious fluid secreted by glands in the worker's head.

As mentioned in the chapter on Life-history (p. 88) the male bees are the product of unfertilised, the females—both queens and workers—of fertilised, eggs. In the architecture of their combs, the perfection of their social life, and the careful tending of their grubs, the Hive-bees are in advance of all other bees and wasps. Too great multiplication of their colonies is prevented by the habit of "swarming." When a young queen emerges from her cell she is killed by the workers or allowed to fight to the death with her mother unless the hive is over-crowded, in which case, the old queen, being prevented by the workers from attacking her daughter, leads off part of the population to found a new community elsewhere (**164, 200**).

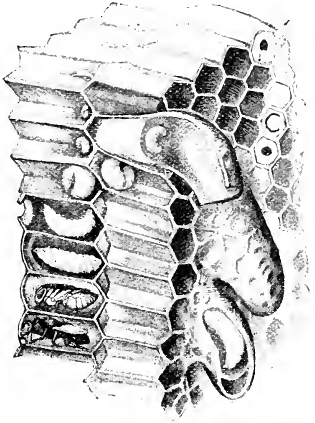

FIG. 176.—Comb of Hive-bee (*Apis mellifica*, L.); to left, egg, larvæ, pupæ, in various stages, and emerging worker; to right, queen-cells. From Benton, Bull. 1 (n.s.), U.S. Dept. Agr., Div. Ent.

Ant-communities also last for several years, but their economy differs in many points from that of the bees. A colony is founded by a single female or by several in association. In some cases these are accompanied by males, and many fully developed individuals of both sexes are to be found in a nest in

addition to the multitude of workers. The latter are wingless, and the females, after their nuptial flight, usually cast or bite off their wings (fig. 153). An ants' nest consists of a complicated system of underground branching tubes and chambers, the tunnels being most skilfully constructed by the workers and often strengthened with small pieces of wood. The well-known Wood Ants (*Formica rufa*) raise a conical hill of earth, through which their galleries run, covering it with fragments of sticks and leaves. Other ants make their nests in hollow trees or old wood. The workers collect honey, fruit-juices and similar food, which they store in their crops and disgorge for the benefit of their comrades who are acting as nurses in the nest, and of the growing grubs, the food being passed from one insect's mouth to another's (163, 164, 196). In a species of tropical American ant (*Myrmecocystus mexicanus*) certain individuals with greatly swollen abdomens serve as living honey-pots for the colony. Other tropical American species (*Atta*, *Cyphomyrmex*, etc.) strip leaves from the trees and carry them to their nests. The leaves are there cut into the tiniest fragments and piled up to form soft, spongy masses on which the ants grow fungi to furnish them with food; over the surface of these "mushroom gardens" are numerous small white bodies formed by masses of swollen ends of the fungus-hyphæ, and produced by the ants through some special cultural process (197).

Slaves and Guests.—The social life of Ants is more highly developed than that of bees and wasps in the relations which they have established with other insects. Some species—*Formica sanguinea* and *Polyergus rufescens* for example—make warlike raids on other ants' nests, whence they carry off cocoons to their own nests, and use the workers as slaves,

employing them to build the masters' habitations and tend the grubs. So dependent have these slave-making ants become through the long practice of their raiding habits that they are unable to work in any way for themselves and perish if deprived of their slaves. A more pleasing feature in ant-communities is seen in the shelter which their nests afford to a multitude of guests, which as a rule render some service to their hosts. The association of ants with Aphids has long been noticed, and the use which they make of the aphids—taking food from the "honey-tubes" of the latter—has been compared to the use which men make of cattle. Ants seek aphids on plants, or at times convey them to their nests; females about to found a fresh colony have even been observed to choose a spot where a few aphids had already settled. The waxy secretion of Coccids, too, is esteemed a luxury by the ants, and those insects are commonly inmates of the nests. Small blind Beetles whose grubs have to be fed by the ant-workers are also occasional guests and are believed to supply their hosts with some sweet secretion. Other inmates appear to act as scavengers, making their living on the ants' excrement. A small Bristle-tail (*Lepismima*) has been observed to play the part of a thief in the ant-commonwealth, lurking beneath the heads of two workers during the passage of disgorged food from one to the other, seizing the drop of fluid and making off with it. The common Red Ants (*Myrmica rubra*) harbour numbers of blind mites; a single worker has been observed to carry about three of these at once, and they are fed by the ants, when they make request by patting the insects with their feet. No service is known to be given by the mites in return for the ants' bounty, but it is hard to believe that they are carried about and fed from pure motives of benevolence (163).

Termites.—It is remarkable that social life among insects should be almost confined to the Hymenoptera. The only other insects in which organised communities are known to exist are the Termites (fig. 178) belonging to the comparatively lowly order of Platyptera. The habits of these insects are in many respects like those of the ants, and they are often known as "white ants," a most misleading term, since structurally they differ as much from ants as beavers do from men. Moreover their communities differ profoundly from the ants' in composition. The young nymphs (fig. 177) are all alike and both males and females may develop into workers (fig. 178 *c*) or soldiers (individuals with large heads and powerful mandibles, fig. 178 *d*); both of these castes are wingless and incapable of reproduction. A "royal pair"—rarely more than one—are the parents of the colony; they are usually confined in a central cell in the nest, having shed their wings after the marriage flight. The "queen" (fig. 178 *a*) is one of the most remarkable of insects, her hind-body being immensely swollen and her ovaries producing eggs at the rate sometimes of one a second. In case of disaster to the royal pair a number of advanced nymphs are kept in readiness to take their place, the reproductive

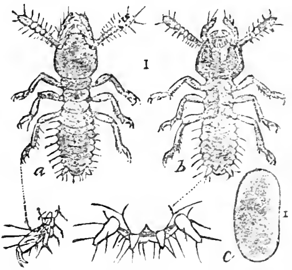

FIG. 177.—*Termes flavipes*, Koll. *a.* newly-hatched nymph, from above; *b.* from beneath; *c.* egg, magnified 20 times; foot and tip of hind-body shown, more highly magnified. From Marlatt, Bull. 4 (n.s.), Div. Ent. U.S. Dept. Agr.

systems of these "substitution royalties" being stimulated to full development by judicious feeding. It is believed that the nature of the food determines in all

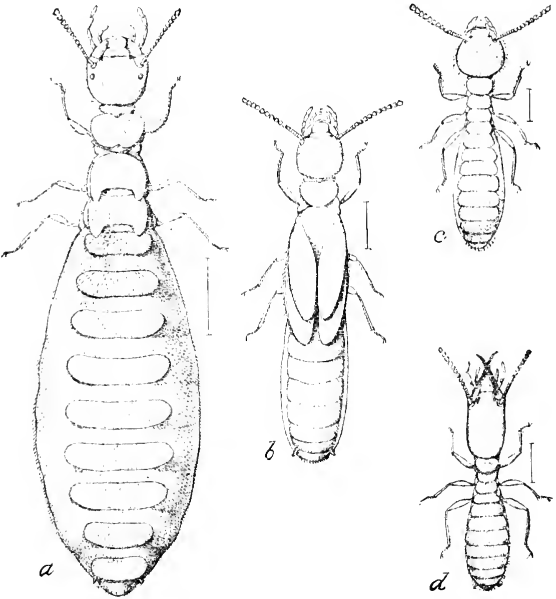

FIG. 178.—Forms of Termites (*Termes flavipes*, Koll.), America. *a.* queen; *b.* female nymph with wing rudiments; *c.* worker; *d.* soldier. Magnified 7 times. From Marlatt, Bull. 4 (n.s.), Div. Ent. U.S. Dept. Agr.

cases whether a young nymph is to grow into a worker, a soldier, or a sexually mature insect. Wood is a favourite food of the termites, but they devour

each other's excrement again and again, as well as food disgorged from the crop, and the spittle of their comrades. When no more nourishment can be got from the waste matter they build it into the wall of their tunnels. They habitually shun the light and open air, making earthen galleries to cover their march across country or their ascent of tree-trunks and wooden buildings. Some of the tropical species raise earthen hill-nests twenty feet high, containing numerous chambers. A termite colony often numbers thousands of individuals, but though the rate of egg production is great, growth proceeds very slowly, and a heavy mortality prevails among them, especially among the mature, winged insects which leave the nests in swarms and mostly fall victims to birds (**3, 113**). It is remarkable that social life among insects should have arisen in orders so far apart in the scale as the Platyptera and the Hymenoptera.

Insect "Royalties."—The use of the terms "king" and "queen" for the fertile male and female members of insect communities has led to the erroneous idea that the government of these communities is monarchial. As a matter of fact it is republican. The queen bee or termite is indeed carefully tended and guarded by the workers, but her actions are, at the same time, restricted by them, and the management of the colony is altogether under their control. No single individual in authority directs the operations of the myriad inhabitants of a nest, yet each works for the good of the whole community.

Insects in relation to Man.—Our survey of insects in relation to their surroundings may fitly conclude with a few words on their importance to mankind. The ravages to crops and fruit-trees caused by plant-feeding insects are often very great;

and the abundant supply of some cultivated plant, through the labours of the husbandman, directly encourages the rapid increase of such destructive kinds. Caterpillars of moths and sawflies, Leaf-beetles and their grubs, Aphids and Scale-insects, devour the foliage or suck sap therefrom, leaving it brown and parched; grubs of Click-beetles and of Crane-flies gnaw at the roots, while the solid wood is riddled by the tunnels of boring-grubs. The damage thus done by insects may be so serious that the only possible remedy is the burning of the plants attacked, in order to stop the further spread of the plague. Sometimes, however, the application of poisonous solutions to the leaves, or of lime to the roots, is found effectual in checking insect-ravages. It is almost needless to point out that a knowledge of the habits and life-histories of injurious insects is of the greatest value to the cultivator who has to fight against them. And it must not be forgotten that he finds allies in those predaceous and parasitic insects which devour the vegetable-feeders. The numbers of the destructive caterpillars are kept down by the ichneumon-grubs, while the grubs of Hovering-flies, Lacewing-flies and Ladybird-beetles, prey upon aphids and coccids. A specially destructive species of coccid accidentally imported several years ago from Australia into California has been largely held in check by the deliberate introduction of a ladybird beetle (fig. 116), its natural enemy (**198, 199, 201**).

As mentioned in the opening pages of this chapter a number of insects of various orders have taken up their abode in human dwellings, and many of these are highly injurious to stored food and wearing apparel, as well as to furniture and wood-work. The ravages of some tropical Ants and Termites in

wooden buildings, are a source of positive danger. More intimate and unpleasant relations with man are established by those insects which, like Gnats, Fleas, Lice and Bugs, draw their food-supply from his body. Flies of the family Muscidæ are now well known to serve as carriers of disease-germs, and the bite of a Mosquito often injects the micro-organism of malaria into the human blood-system. The maggots of flies however must generally be regarded as of considerable indirect service to man, by devouring decaying substances which might otherwise cause serious disease. In the same way the action of the Silphidæ and other carrion-feeding beetles is highly beneficial. And if some insects destroy fruit-trees others, specially Bees, by their action on the flowers, ensure the ripening of the fruit.

Comparatively few insects can be recognised as directly serviceable to us. Some species are habitually eaten in warm countries—locusts in the East, and water-bugs in Mexico. Several kinds of soft-skinned beetles have been used medicinally to raise blisters; the gall of a south European Gall-fly (*Cynips tinctoria*) serves in the manufacture of ink, but its use is now largely supplanted by chemical processes. A Scale-insect (*Coccus cacti*) produces the well-known cochineal red dye, while to another insect of the same family (*Carteria lacca*) we are indebted for lac. Of very great importance is the Common Silkworm (fig. 66), the caterpillar of the moth *Bombyx mori* (fig. 136), so largely cultivated in southern Europe; as also the caterpillars of several large Saturniid moths which are reared in the east for purposes of silk-production. To the secretion of these caterpillars we owe the immense quantity of silk used in commerce and the arts. And lastly we have in the Hive-bee a thoroughly domesticated

insect which provides us with useful wax, and with sweet and wholesome honey (**200**). The life of insects therefore touches human life in many ways, and their study, of high interest for its own sake, derives added importance through its bearings on the health, the labour and the pleasure of mankind.

Chapter VI

THE PEDIGREE OF INSECTS

It is interesting to contemplate a tangled bank . . . with various insects flitting about . . . and to reflect that these elaborately constructed forms . . . have all been produced by laws acting around us. . . . There is grandeur in this view of life with its several powers having been originally breathed by the Creator into a few forms or into one; and that . . . from so simple a beginning, endless forms, most beautiful and most wonderful, have been and are being evolved.—DARWIN.

Relationships of the Insect-Orders.—The facts set forth in the preceding chapters about the form, life-histories, classification and habits of insects, give but the outline of a vast subject. It remains to review briefly this outline that has been sketched, and to seek for the meaning of the facts before us. In so far as we interpret them correctly we shall catch glimpses of the path by which the insect-races have come to be as they are to-day; we shall, in a measure at least, be enabled to trace their pedigree.

In the first place it is necessary to gain some idea as to the relationships between the various orders of insects. Which of them represent high and which lowly twigs on their branch of the great tree of life? Do any of the living insects of to-day retain unchanged the characters of remote ancestors? that is to say, can any existing group of insects be regarded as truly primitive? In answering such questions as these, two principles are admitted by well-nigh all students of animal life. Animals

which show generalised structure are believed to be more ancient than those which exhibit great specialisation. And the life-history of the individual is believed to indicate to some extent the life of the race. For example an insect like a Termite with four similar wings is considered lower or more primitive than one like a House-fly in which the hind-wings are represented by stalked knobs. And the fact that rudiments of limbs appear on the abdominal segments of many insect embryos is thought to indicate that the remote ancestors of insects had legs on the hind-body as well as on the thorax. But these two principles must be used with the greatest care, and especially in the study of insects. So many insects are clearly degenerate that the naturalist must always consider the possibility of generalised structure pointing to degradation rather than to antiquity. And the striking changes which many insects pass through after hatching greatly complicate the task of interpreting their life-histories.

Reference has already been made (Chapter IV, p. 164) to the various large divisions into which it has been proposed to group the insect orders. The Mandibulata, or insects with biting jaws, are, on the whole, lower than the Haustellata or insects with jaws adapted for piercing or sucking, since in the latter the individual jaws are so highly modified that their typical parts can be recognised only with great difficulty or not at all. A Moth is distinctly a higher insect than a Cockroach. But is it possible absolutely to settle the position of insects by this test? Is a Beetle, for instance, a lower insect than a Bug? Turning to the other chief division of the insect-orders which has been proposed—that which depends on the life-history—we remember that the bug comes into

the Ametabola and the beetle into the Holometabola. And the facts of insect development (Chapter II) clearly indicate, as we have seen, that complete metamorphosis with a resting pupal stage is an advance on direct growth throughout which the insect moves and feeds. If then a bug's jaws are more highly specialised than a beetle's, the latter's life-history is more highly specialised than the former's.

It is clear then that different classes of facts often point to divergent conclusions, and that a careful weighing of all available evidence is needful if we are not to be misled. Is the nature of the life-history a more important character than the form of the jaws? The examination of the characters presented by insects within a single order seems to show us that it is. Among the Hymenoptera for instance there is very considerable difference in jaw-structure, but every member of the order passes through a complete metamorphosis with a free pupal stage. Therefore, in the list of orders given in Chapter IV, the arrangement founded on life-histories was followed, the Ametabola (lowest) coming first, the Hemimetabola next, and the Holometabola (highest) last. But no linear arrangement can represent truly relationships best symbolised by the branching of a tree, any more than a railway time-table, wherein the names of the stations are arranged in vertical columns, can indicate the geography of a line. A shoot arising low down on a branch may send out twigs which overtop the lower twigs of a shoot whose origin is higher. Such a conception may symbolise the difficulty presented by the comparison of the beetle and the bug.

Collembola and Thysanura.—It has been already mentioned (p. 164) that the Collembola and Thysanura have been separated from all other insects as Aptery-

gogenea on account of the belief that absence of wings among them is a primitive character, and not the result of degradation. No species of either order is known to possess the vestige of a wing. While giving due weight to this evidence it may be doubted whether primitive winglessness, even if admitted, can be looked upon as a primary dividing character among insects. The Collembola, at any rate, cannot be regarded as a primitive group. The in-pushing of the head-skeleton so that the jaws appear to be inside it, and the reduction of the abdominal segments to five or six, show very decided specialisation, as do the presence of the spring—a most curious organ unknown in any other group of insects—and the post-antennal sense-organ, also peculiar to the order. Moreover, the families of Collembola are fairly rich in genera and species, mostly with a very wide and continuous range. On the whole the Collembola must be regarded as a group of insects, in some respects specialised, in others degraded, in correspondence with their life in concealed and underground situations. And it must be remembered that life in such situations would certainly tend to the total loss of wings.

The Thysanura, on the other hand, have more claim to be considered primitive. They have the full number of abdominal segments, many of which bear short limbs, while the jaws in the less degraded forms are similar to those of the normal biting insect. Moreover, they are clearly a decadent group, each family containing as a rule but one or two genera. Taking all the facts into consideration the Thysanura must undoubtedly be regarded as the lowest of living insects. And it is interesting to notice that in those genera—Campodea and Iapyx—which live in the most obscure situations, such apparent retraction of

the jaws into the head as characterises the Collembola has taken place; while one of these genera, Campodea, is the only insect known to retain in adult life a pair of tubercles representing the tritocerebral appendages of the embryo (103). The ectotrophous Thysanura then furnish us with a provisional starting-point for our higher insect orders, while the entotrophous division leads on—though only for a very short way—towards the lowly divergent shoot of the Collembola (206).

Dermaptera, Orthoptera, and Platyptera.—The Dermaptera, Orthoptera and Platyptera, have many structural features in common and may be considered together. All have normal biting jaws, the second maxillæ being as a rule incompletely fused. Most have ten evident abdominal segments with appendages on the tenth. All attain the perfect state without any marked change of form. Comparing the three orders, the Dermaptera are seen to retain a markedly primitive character in their mesodermal genital ducts, though their wings are highly specialised. In the close likeness between the fore and hind-wings the Termitidæ, a family of Platyptera, show the most primitive condition of those organs among the three orders. In the Orthoptera and the Perlaria the hind-wings are specialised by the presence of a folding anal area, but most of the insects of these groups retain the primitive long jointed cercopods so characteristic of the Thysanura. The aquatic nymphal life of the Perlaria, however, marks them off distinctly from the Orthoptera and foreshadows the orders (Plectoptera and Odonata) with aquatic larvæ. In the Orthoptera are to be found the most vigorous development of species, and the most marked specialisation of structure within the section we are considering, and they on the whole must be considered higher than the other two, though

generalised and specialised characters are mixed in all three. The wingless forms are clearly degraded. The Termites, an ancient and well-defined family, owe their survival to their adoption of the social habit. The presence of long, jointed cercopods as the precursors of forceps in at least one species of Earwig suggests a thysanuroid ancestor for the entire group.

Thysanoptera and Hemiptera.—The Thysanoptera which have been united by some authors with the Platyptera, by others with the Hemiptera, are clearly intermediate between the group which we have just considered and the last-named order. Their small size and the reduction or absence of wings stamps them as a degraded order; but the structure of their jaws marks a stage between the normal biting organs of the Platyptera and the sucking and piercing mouth-parts of a Bug; the mandibles are converted into stylets, though the maxillæ retain their palps. The Thysanoptera then may be regarded as a degraded offshoot from the extinct ancestors of the Hemiptera, these ancestors being themselves derived from primitive mandibulate insects. Except for the connection with the Thysanoptera just suggested the Hemiptera are one of the most isolated of insect-orders; with little or no metamorphosis we find a high specialisation of adult structure, with great variety and flexibility in details so that the order contains many families and multitudinous species. Not the mandibles only as in the Thysanoptera, but the first maxillæ also are developed as stylets, while the second maxillæ unite to form a tube wherein these piercers work; the palps, almost always absent, remaining rarely in a vestigial state. Associated with this specialised and characteristic mouth is to be found the greatest variety in form of body, development of wings, and habit. It is of special interest to notice that those sub-orders

(Heteroptera and Anoplura) wherein the wings have undergone the greatest modification or degradation, retain a simple, direct life-history, while in that whose fore and hind-wings remain less differentiated (Homoptera) a larval stage markedly differing from the imago is sometimes present, and rarely (male Coccidæ) a resting pupal stage also.

Plectoptera and Odonata. The Plectoptera and Odonata agree in passing through an aquatic larval stage, but differ greatly in the form of their larvæ as well as in their structure as imagos. In their permanently paired genital ducts the Mayflies exhibit an ancient character which has been retained by no other winged insects, while their larvæ suggest Bristletails adapted for life in the water. But the specialisation of their wings and sense-organs and the complete division of labour between the larval and perfect stages forbid us to consider them as, on the whole, a primitive group. Mayflies as well as Dragonflies, whose specialisation both in the larval and perfect condition is most marked, must be regarded as isolated off-shoots from the primitive mandibulate stock, giving but few hints as to the course of their evolution.

Origin of Wings.—It has been suggested however that the aquatic larva of a Mayfly represents closely the ancestral stock whence all insects have sprung, since life in the waters preceded life on the land. And a brilliant speculation (**202**) has indicated pairs of tracheal gills on the meso- and metathorax as the possible origin of insect wings. The primeval insects forsook, so it is thought, the water for the land; and the plates, becoming useless for breathing, were enlarged and finally changed into organs of flight. In the preceding chapter (pp. 285-94) reasons have been given for considering insects, as primarily creatures of the land and the air, those which live

either wholly or partly in the water, being probably invaders from the shore. The immense majority of insects are terrestrial or aerial, and the aquatic forms appear to have been modified from their land relations. Such evidence is admitted by zoologists as conclusively showing the native element of any class of animals; mammals are universally regarded as primarily terrestrial, though seals and whales are marine, crustaceans as aquatic, though some crabs and wood-lice live on land. It may be admitted readily that life began in the water, and that to the waters we must go for the remote progenitors of insects. But the class as we know it now is composed of typically land-animals, and we have every reason to believe that its immediate ancestors were air-breathers (**170**).

But while denying that the aquatic grub of a Mayfly represents the primitive insect it is still possible to regard it as indicating the precursor of *winged* insects. That is to say it may be held that some of the primitive wingless air-breathing insects took to an aquatic life and developed tracheal gills, which, on transference to the upper air, became changed into wings. But the fact that the majority of winged insects are terrestrial and aerial, and that similar adaptations to aquatic life are found in the larvæ of different orders—presumably therefore independently and secondarily acquired—tells even against this view. The origin of insect wings must at present be considered a mystery. In all the orders as yet reviewed in this chapter wings arise as outgrowths from the tergites of the second and third thoracic segments, beginning as simple expansions of the tergal plate. Assuming that wings arose thus in primitive air-breathing insects it has been suggested that originally, before they became large enough for flight, they may have served for respiration in a damp

atmosphere, or as sails or parachutes (**2**), assisting their possessors to take flying leaps through the air.

Insects of Past Ages.—From our survey of the lower orders of insects living around us to-day we have tried to trace out the relationships which they bear to each other. It will be well to test our results by the facts available regarding the insects of past ages of the earth's history, the insects whose fossil remains are preserved for us in the rocks (**203-5**). Fossil insects are somewhat rare; as with other land animals their preservation in sedimentary deposits is less likely than in the case of inhabitants of the sea. Still, enough insect remains have been preserved and discovered to help us to trace in part the history of the class through geological time.[1] It is disappointing to find that the oldest known fossil insects do not bring us much nearer to a solution of the problem of wing-origin. They do however indicate clearly that similarity between the fore and hind-wings is an ancient character. A large number of remains from the Carboniferous rocks of France and North America prove that, in that remote period, lived a

[1] For readers unfamiliar with geological terminology the appended table of the great periods and formations may be useful for reference. The formations become more ancient from above downwards.

Tertiary or Cainozoic.	Pleistocene. Pliocene. Miocene. Oligocene. Eocene.
Secondary or Mesozoic.	Cretaceous. Jurassic. Triassic.
Primary or Palæozoic.	Permian. Carboniferous. Devonian. Silurian. Ordovician. Cambrian. Archæan.

race of insects with the general build and appearance of modern Cockroaches (1), but with transparent fore-wings, the hind-wings being similar and without a folding anal area. The wing-neuration is of a simplified orthopterous type, five principal longitudinal nervures being present in both fore and hind-wings; in the fore-wings of modern cockroaches the number is reduced to four though the hind-wings retain five. A wing-fragment with similar orthopteroid neuration has been discovered in the Silurian rocks of northern France; this is the oldest insect-fossil known to us.

In Secondary rocks—Triassic and Liassic—remains are found with wings intermediate in structure between those of the Carboniferous types and those of modern Cockroaches, the differentiation between the fore- and hind-wings having begun. It may be regarded then as certain that our living Orthoptera are the specialised descendants of insects of the Primary epoch, with four similar membranous wings. For not the Blattidæ only, but the Phasmidæ and Locustidæ appear to have had, in Carboniferous times, ancestors whose fore-wings had not yet become firm in texture and whose hind-wings had no folding anal area. We find therefore that if the insects of the Primary epoch be taken into account the main distinction between Orthoptera and Platyptera[1] breaks down, and we are able with confidence to look back to common ancestors for both orders, probably with simple body-form like a modern termite, four similar

[1] On account of the similarity of their two pairs of wings it has been proposed (203) to class all Palæozoic insects in a special order—Palæodictyoptera. As these insects, however, are clearly related to existing families of our Orthoptera and Platyptera (205) it is better either to distribute these extinct families according to their affinities between those two orders, or to unite the living Orthoptera, Platyptera and the fossils, into one single order.

transparent wings with simple orthopteroid neuration, and a pair of long, jointed cercopods.

Nearer to the Platyptera, also, than to any other living insects, must be placed an extinct Carboniferous group (3, 204) including the genera *Corydaloides*, *Lithomantis*, *Dictyoneura*, and *Haplophebium*. Many of these had paired veined outgrowths on the hind-body segments, which have been interpreted as tracheal gills comparable to those found on the imago of the living Perlid *Pteronarcys*, but more numerous, much more highly developed, and undoubtedly functional. Some of these ancient insects moreover had short wing-like expansions on the pronotum. They had two pairs of large membranous wings, and it is hard therefore to believe that they were aquatic in habit when adult. Probably the gill-like plates on the abdomen were of use in breathing damp air, and may have been survivals from a larval stage passed in the water. Or these paired outgrowths on the first thoracic and the abdominal segments may perhaps suggest that the rudiments of wings appeared on every segment of the primitive insect's body, but that only on the meso- and the metathorax did they develop into organs of flight.

Some insects (*Homaloneura*, etc.) of Carboniferous age, closely resembling those just described, with similar fore- and hind-wings and prothoracic and abdominal wing-rudiments or gill-plates, have been regarded as the ancestors of Mayflies. These *Protephemeridæ* had excessively long cercopods. They do not show, however, any other characteristic ephemerid features; and they can have had but little to do with the origin of Mayflies if the contemporary Carboniferous *Palingenia Feistmantelli* is rightly referred to an existing genus of Ephemeridæ. There is no doubt that Mayflies closely resembling those now living were

already developed in the early Jurassic (Lias) period. In rocks of Jurassic age also remains of Dragonflies, both imagos and larvæ, referable to the existing families, are fairly abundant. Going back again to the Carboniferous rocks of France, gigantic insects have been discovered with a general likeness to living dragonflies, but with less specialised thoracic segments and simpler wing-neuration (**204**). These may perhaps be regarded as a link between the recent Odonata and their far-off Platypteroid ancestors. Some fragments of wings from Devonian rocks have been also referred to the precursors of Dragonflies.

A fossil insect of Devonian age (*Eugereon Böckingi*) furnishes an interesting link in the history of the Hemiptera. Its jaws appear to have been almost typically hemipterous in structure, but its wings were like those of the primitive orthopteroid insects just mentioned (**203**). It points to orthopteroid or platypteroid forms as the ancestors of the Hemiptera, while it seems to indicate clearly that the hemipterous mouth had been developed before the modifications in wing-structure which characterise the existing suborders of Hemiptera had appeared. In the Carboniferous rocks of North America a wing (*Phthanocoris occidentalis*) has been found which shows a decided approach to the fore-wing of the recent Heteroptera, presenting a large firm corium, a narrow clavus, and a terminal membrane (**203**). Coming into the Secondary epoch we find that the existing families of Fulgoridæ and Aphidæ were already existing in the Oolite, and Cicadidæ as early as the Lias. Of the Heteroptera the Coreidæ and Lygæidæ can be traced back to the Lias and the Nepidæ and Reduviidæ to the Oolite; the other families are only certainly represented in Tertiary rocks, where the few known fosil Thysanoptera also occur (**203**).

Origin of Metamorphosis.—The fossil remains of holometabolous insects resemble so closely those now living that they can be readily considered in our review of the orders to which they belong. It may be mentioned however, that except a few Carboniferous fossils referred to the Coleoptera, there is no evidence for the existence of insects with complete metamorphosis before the Secondary epoch. What geological testimony we have, therefore, confirms the impression derived from the study of living insects that the metamorphic orders are the highest. Before surveying these orders it will be well to devote a short space to the difficult question of how insect metamorphosis arose.

It is well known that a vast number of animals are hatched from the egg in a state very unlike that of their parents, passing through marked changes of form before reaching their full growth. Starfishes, Crabs and Oysters, are sufficiently familiar examples drawn from different great Branches of the animal world. But these are marine animals which produce eggs with a small supply of yolk. Fresh-water animals, as a rule, undergó less marked transformations than their marine relations, while land animals are almost always hatched or born in a form closely like their parents, who produce large eggs with plentiful yolk or otherwise provide for the full development of their offspring. Generally speaking, metamorphosis among animals is confined to dwellers in the water, who produce multitudinous young, and turn them out while still undeveloped to shift for themselves. The transformations of insects, a typically air-breathing class, present therefore an exceptional and puzzling problem (**71**).

The insect-larva has often been represented as a prematurely hatched embryo which leaves the egg

to complete its growth in the outer world, as do the young of the marine animals just mentioned. Doubtless the larva represents in some respects an older stage in evolution than the perfect insect. But it is a well-developed animal which cannot, only because it has yet no wings, be compared for a moment with the free-swimming gastrula of a starfish or the veliger of a water-snail. It has therefore been suggested, on the other hand, that the insect-larva represents the primitive adult insect, and that the transformations through which it passes are entirely post-embryonic, comparable for example to the growth of antlers in the stag (71).

This latter view receives strong confirmation from the striking fact that no insect of any order is hatched in the winged state. The way in which wings are acquired varies greatly, but they are never fully developed until late in life. It seems certain, therefore, that the growth of wings after hatching has always been exhibited by the class, and that we may safely take the development of the Cockroach as a type of what occurred among the first winged insects. In the second chapter evidence was brought forward to show that the campodeiform larva is more ancient than the eruciform; and the few instances, such as the Meloidæ and Stylopidæ, in which the campodeiform precedes the eruciform grub in the life-history of the same insect (see p. 110), clearly shows that the latter form was gradually adopted with changing conditions of larval life. As the higher insects exhibited greater and greater divergence of habits and surroundings in the winged and wingless stages of their life-history, larva and imago became more and more divergent in structure, and the resting pupal stage with its profound internal changes became an absolute necessity as a connecting link between the

two. We have already seen (Chapter II, pp. 116-8) how several stages of transition from the active nymph to the passive pupa can be traced, thus bridging, at least to some extent, the gap between incomplete and complete metamorphosis. But it has recently been pointed out that a deeper distinction than the nature of the pre-imaginal instar marks off the metamorphic insects from the lower orders; in the nymphs of the latter the wing-rudiments are always visible outside the body, in the larvæ of the former they are always concealed within, appearing only at the pupal stage (69). This distinction, however, becomes less marked when we remember that in insects which do not undergo a complete transformation the wing-rudiments first arise beneath the skin of an early instar though they soon appear outside the body. It is not hard to conceive how, as the habits of the young insect diverged more and more from those of the parent, the appearance of the wing-rudiments outside the skin would be put off to a later and later stage. And the recent observation of visible wing-rudiments occasionally appearing on the full-grown grub of a beetle (*Tenebrio*) shows that in the ancestors of the Coleoptera the wings grew outside the body (79). Starting then with no greater change than the acquisition of wings after hatching, an opposite modification of the wingless and winged stages in the life-history independently of each other has led to the startling transformations now passed through by all the higher insects. And it has thus come to pass that, in contradiction to the prevailing rule among animals, the highest insects undergo the most marked changes of form.

Neuroptera and Coleoptera.—The above suggestions as to the origin of metamorphosis among insects point clearly to the Neuroptera and Coleoptera as the

most ancient of the metabolic orders. In some families of Beetles the campodeiform larva is to be found almost in its primitive state; in others a markedly eruciform type has been developed. It is of interest to notice that, as a rule, those Coleoptera with the most highly modified larvæ are distinguished in the perfect state by a reduction in the primitive number (five) of tarsal segments. Among the Neuroptera the eruciform larva has only been assumed in a single family (Panorpidæ), but the campodeiform larva has undergone more specialisation than among the Beetles; the cercopods have disappeared and the jaws have become adapted for suction by the grooving of the mandibles. In the perfect state the Neuroptera have retained many ancient characters, the wings of the two pairs being alike, and the abdominal segments but little modified. The fore-wings of the Coleoptera, on the other hand, have undergone greater changes than those of any other insects, by becoming transformed into dense chitinised elytra. With this exception, however, the Beetles are not a highly specialised order; the biting mouth is retained, the number of abdominal segments is only slightly reduced, and the prothorax remains distinct as in the lower insects. It seems, therefore, that we are justified in regarding the Neuroptera and Coleoptera as off-shoots from a common stock. And if we attempt to reconstruct the presumed ancestor by uniting the most primitive characters in the two orders, by imagining, for instance, an insect with the body-form of the oil-beetle's active larva, provided with four similar net-veined wings, we realise the probability that the Neuroptera and Coleoptera of to-day are the descendants of the Platypteroid insects of the Primary epoch.

We are compelled to go back some distance in the Primary period for the ancestors of the oldest meta-

morphic insects, since the discovery of elytra in the Carboniferous rocks of Germany shows that the Coleoptera were already differentiated in later Palæozoic times. And in the Trias of Switzerland undoubted remains of weevils have been found, proving that a family with eruciform larvæ had arisen in the earliest of the Secondary periods. The Chrysomelidæ and Buprestidæ also can be traced back to the Trias and the Carabidæ, Elateridæ, Cerambycidæ and Scarabæidæ to the Lias (203). Clearly, therefore, the beetles had not only become differentiated as an order, but were already being specialised into the principal existing families at the close of the Primary epoch. The Neuroptera as we know them to-day cannot be traced back as far as the Beetles, but remains of Sialidæ and Panorpidæ occur in Liassic, and of Chrysopidæ in Oolitic rocks.

Trichoptera and Lepidoptera.—Reference has already been made to the close relationship between the Trichoptera and the Lepidoptera (Chapter III, pp. 156-8), the lowest family (Micropterygidæ) referred to the latter order resembling Caddis-flies in the possession of functional mandibles in the pupa, and laciniæ in the first maxillæ of the imago. The pupæ of Trichoptera are free, and become active in preparation for the final change, while among the Lepidoptera a transition from this state of things can be traced as we ascend in the scale of the families to an obtect pupa with two or three abdominal segments alone capable of motion. The larvæ in both orders are eruciform, but while those of Caddis-flies are almost all aquatic, those of Moths and Butterflies are, almost without exception, arboreal, and as a necessary adaptation for life on twigs and branches of trees and herbs, are provided with clasping prolegs on the hind-body. Turning to the wing-structure

of the imago it is found that in three families of moths (Micropterygidæ, Eriocraniidæ, and Hepialidæ) the neuration of the hind-wings is as complex as that of the fore-wings, at whose base is a fold in the membrane (jugum); these features are characteristic of the Caddis-flies. There seems no doubt therefore that the Lepidoptera must be derived from Trichopteroid ancestors. And the difference in the larval structure and habits shows clearly that the primitive moths diverged from the primitive caddis-flies before the grubs of the latter had taken to an aquatic life. Fossil remains of insects of these two orders are extremely rare, but we know that moths with sucking-tubes like those of modern Sphingidæ already lived in Oolitic times. The wing-neuration of some of these Secondary insects was like that of modern Cossidæ, but it is only in Tertiary beds that remains of Lepidoptera clearly referable to existing families have been found. Fossil wings of insects believed to have been Caddis-flies occur as early as the Lias; they resemble in their neuration the wings from the same rocks which are referred to the Panorpidæ. And the Panorpidæ—the only family of Neuroptera with eruciform larvæ—give us a hint of the vanished insects which must have connected the common ancestors of modern moths and caddis-flies with the primitive Neuropteroid stock.

Hymenoptera and Diptera.—The Hymenoptera and Diptera must undoubtedly be regarded as the most highly modified of all insects, the former order in some respects, the latter in others, having reached a farther degree of development. In the structure of the jaws the Hymenoptera are comparatively primitive, most of the families retain the biting mandibles; and the specialised sucking and working mouth-parts of the higher Bees are formed by enlargement or reduc-

tion of typical parts of the primitive jaws rather than by such startling transformations as have produced the sucking-tube of Moths. On the other hand the union of the first hind-body segment with the thoracic capsule is a peculiar feature unknown in any other insects; and in the higher families this specialisation of the fore-body is accompanied by the remarkable constriction of the succeeding abdominal segments which gives rise to the characteristic "waist" of wasps and ants. In the larval stage a transition can be traced from the sawfly caterpillars, closely like those of moths, to the legless maggots of ichneumon flies and bees, but, throughout the order, the larval head is well-developed. Among the Diptera the larvæ have without exception lost their primitive limbs, though some possess special sucker-feet or "pro-legs," while in the extremely degraded maggots of the Muscidæ and allied families the head region is represented only by a protrusible proboscis with hooks. The body of the imago is always highly specialised. The mandibles are present as piercers or altogether suppressed, while the sucker is so far modified that it is a disputed point whether it is composed of the first or the second maxillæ; the hind-wings are reduced to small, stalked knobs. From the lower families of Diptera—the Crane-flies for example—to the higher—such as the Muscidæ—a condensation of the body-segments can be traced accompanied by a simplification of wing-neuration, and a modification of the feelers from a typical, many-jointed, thread-like form to the short antenna of a blow-fly with its three specialised segments.

The Hymenoptera and Diptera are not nearly related to each other and either order is so isolated that it is hard to suggest what their affinities to other insects may be. There is not much evidence from

fossils to help in the solution of the question. The highest families of the Hymenoptera—Ants, Wasps and Bees—were abundant in Miocene times and, if the determination of certain obscure Lias and Oolite fossils can be trusted, ants had already appeared in the Secondary epoch. Remains of some lower Diptera (Tipulidæ, Asilidæ) occur as early as the Lias, but there is no certain evidence of the existence of the higher families until Tertiary times (**203**). The wing-neuration of the Tipulidæ recalls that of the Panorpidæ and the Trichoptera; and it is possible that the primitive Diptera branched off at the close of the Primary epoch from the stock which, as we have already seen, must have given rise to the caddis-flies and moths. The origin of the Hymenoptera must probably be sought farther back in the history of the metamorphic insects; their marked specialisation of body-form, development and habit, united with the retention of comparatively primitive jaws suggest that they must have arisen early from the old neuropteroid stock. The likeness between the caterpillars of moths and those of sawflies which might be supposed to indicate affinity between the Hymenoptera and Lepidoptera is better explained as the result of adaptation to similar habits and surroundings.

Insects and other Arthropods.—Our comparison of the various Orders with one another has led us back to thysanuroid forms which must have lived in early Primary times, as the probable ancestors of all insects. But except for the absence of wings these primitive creatures showed all the leading features of the Class as we know it to-day. For the common origin of Insects and other Arthropods we must look further back still, to a period when fossil evidence fails us altogether. The problem of the relationship of the Insects to other classes of their

Branch can be solved only by means of the facts drawn from a study of structure and life-history. There are a few points in the embryonic growth of insects which help us to realise the form of their ancestral stock a little earlier in the history of life's unfolding, than the evidence of fossils can carry us back. The vestigial appendages between the feelers and mandibles, and on the abdominal segments, together with the manner of growth of the cercopods (pp. 93-4), show that the progenitors of six-legged insects had a head bearing five pairs of appendages, and a body of fifteen segments, whereof all but the last carried limbs. The limbs of the first three body-segments (the walking-legs of modern insects) and of the fourteenth (the cercopods) must, at an early period, have become more important than the intervening pairs, which now survive only as the vestigial limbs of Bristletails. These many-legged animals which, we must believe, preceded our six-legged insects, can now be compared with other classes of Arthropods.

Symphyla. — The closest general likeness to insects among animals not actually classed with them is to be seen among some small, fragile, white creatures, living in damp earth and similar concealed situations, with a head carrying a pair of feelers, a pair of mandibles, and two pairs of maxillæ, and an evenly segmented body with fourteen pairs of limbs. These little animals make up the single genus *Scolopendrella*, and they are usually reckoned as a distinct class — Symphyla — though their affinity to the Thysanura is probable (2). The head and its appendages probably correspond with those of a typical insect, the original five pairs being reduced to four, though both pairs of maxillæ are to a great extent fused together ; while the number

of limb-bearing body-segments is fourteen, as in our supposed primitive insect. The legs on the first nine abdominal segments, which in the Thysanura are vestigial, and in other insects absent, are retained in the Symphyla; then come a pair of reduced limbs with sense-organs, while the hindmost appendages are conical, unjointed cercopods with silk-glands opening at their tips (fig. 179). These frail creatures, therefore, give a fair idea of the progenitors of insects; their structure seems to indicate that the second head-appendages had disappeared before the abdominal limbs began to shorten, and the distinction between thorax and hind-body to appear. The most marked feature wherein they differ from Insects is the forward position of the genital opening which is beneath the fourth body-segment in both sexes (**206, 207**).

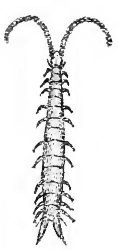

FIG. 179. — *Scolopendrella immaculata*, Newp. Magnified 6 times. After Latzel, "Die Myriopoden."

Chilopoda. — The true Centipedes (Chilopoda) also present several points of affinity with Insects. The head of a centipede bears a pair of feelers, a pair of mandibles, and two pairs of maxillæ; and the presence of vestigial appendages in the embryo between feelers and mandibles brings the primitive chilopod head into correspondence with that of the primitive insect (**210, 217**). The position and form of these vanished appendages in the developing centipede suggests that they were a second pair of feelers. The limbs of the first body-segment in a centipede are modified into powerful poison-jaws for seizing prey, and there follow at least fifteen pairs of leg-bearing segments, and sometimes more than a hundred and fifty. The extreme variation of the number of body-segments in centipedes shows that this character

has but little value as a sign of their relationships. But there is no improbability in the idea that the class may have arisen from the fourteen-legged animals indicated above as the progenitors of insects, the head with five pairs of appendages being common to both classes. Among the insects, however, there has been a tendency towards reduction in the number of the body-segments; among centipedes towards an increase (fig. 180). No undoubted centipedes are known earlier than Oligocene times, but in the Carboniferous group (Protosyngnatha) which is believed to represent their progenitors, the number of body-segments was fewer than in living forms (**203**).

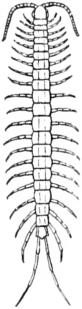

Fig. 180.—Centipede (*Rhysida rugulosa*, Poc.). Half natural size.

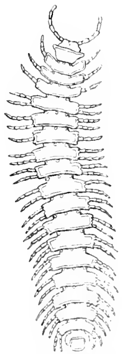

Fig. 181.—Millipede (*Platyrhachus mirandus*, Poc.). Half natural size.

After Pocock in Weber's "Zool. Ergeb. Niederl. Ost-Indien."

Diplopoda.—The Millipedes (Diplopoda) differ from Insects in having apparently only three pairs of appendages on the head of the adult instead of four; these are the feelers, the mandibles, and a plate-like lower lip, formed by the fusion of a single pair of maxillæ (though according to some authorities two pairs are present). The number of body-segments is large and variable; for the most part they become fused together in couples so that each apparent segment bears two pairs of legs (fig. 181). Fossil

Millipedes closely like those now living have been found in Oligocene rocks, while remains of their progenitors, showing the gradual progress of the compound segments, can be traced through the Primary formations from the Devonian to the Permian. The recent discovery (**210**) of an embryonic segment, distinct, though without appendages, behind the maxillary segment, goes far to bring the head of a millipede into correspondence with that of a centipede or an insect; and we can probably regard the class as springing from ancestors something like Scolopendrella. That the affinity of Centipedes and Insects to each other is greater than that of either to the Millipedes is shown by the position of the genital openings being far forward in the body among the latter animals (as in Scolopendrella) and near the hinder-end in the two former classes (**209**). The fact that some millipedes are hatched from the egg as six-legged larvæ has often been urged in support of their close relationship with Insects. But these limbs cannot correspond with the six legs of an insect since they are not borne on successive segments, and the segments whereon they do occur are not always constant in the various species of Millipedes.

Arachnida.—The Scorpions, Spiders, Mites, and other orders of Arthropods which make up the class Arachnida are sharply marked off from Millipedes, Centipedes, and Insects, by the absence of a distinct head and of feelers. The head and fore-body segments are fused together, at least in part, to form a cephalothorax which carries six pairs of appendages, whereof the first two are usually seizing-jaws, and the last four walking-legs. It is likely that these six pairs of limbs correspond with the jaws and legs of insects, since vestiges of at least one pair of feelers and two or three head-segments without appendages

have been detected in the embryo of a spider (**211**). In the lower Arachnids, the Scorpions (fig. 182) for example, there are twelve distinct segments in the hind-body; and limbs on certain of these segments are preserved in many living arachnids, the pectines of Scorpions, the gill-plates of Limulus, and the spinnerets of Spiders, being well-known examples. There is much reason therefore for believing that arachnids, like insects, have been derived from an ancestor with nineteen limb-bearing segments. Many arachnids, the higher Spiders and the Mites, for example, breathe, as

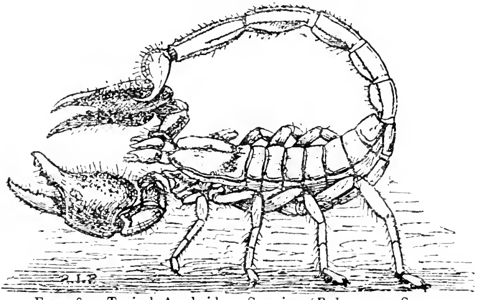

FIG. 182.—Typical Arachnid—a Scorpion (*Palamnæus Swammerdamii*). From Pocock, Natural Science, vol. 9.

insects do, by means of tracheal air-tubes, and on this ground a rather close relationship between the two classes has been advocated by some students (**214, 216**). But the more generalised arachnids either live in the water, breathing by gills on some of the abdominal limbs (Limulus and the extinct Eurypterids); or are land-animals (Scorpions, Pedipalps and the lower Spiders), breathing air by internal "lung-books" which agree in position and essential structure with the gills of their marine relations (**208, 215**). It seems clear therefore

that the primitive Arachnids arose from the Arthropod branch before an aquatic had been exchanged for a terrestrial life, and that the tracheal air-tubes in Insects, Centipedes, and Millipedes on the one hand, and in the higher Arachnids on the other, must be regarded as independently acquired (**208**). There is fossil evidence for the existence of marine arachnids (Eurypterids) in Ordovician, and of Scorpions in Silurian, times, proving conclusively that for the common origin of Insects and Arachnids we must go back to an immensely remote period.

Crustacea.—It has already been admitted (p. 351) that, while the immediate progenitors of insects were air-breathing animals their more remote ancestors must have lived in the water. We have just seen that there is undoubted evidence for a true relationship between Insects and Arachnids, and that the latter class in all probability had a marine origin. There is another great class of arthropods, the Crustacea—including the Lobsters, Crabs, Barnacles, Water-fleas and their allies—to be considered, which is almost entirely aquatic. Can any clear relationship be established between these animals and insects? A likeness between certain insect-larvæ and the immature forms of Crustacea was at one time believed to indicate affinity between the two classes; but the view does not now find much acceptance. It is generally admitted that all Arthropods must be traced back to segmented worms, but it is believed by many students that the Crustacea have come off independently of the other classes, and that the structural features which characterise arthropods as a whole—the chitinised skin, the jointed limbs, the reduced coelom, the heart with paired openings, the large fore- and hind-guts—have been independently acquired by the air-breathing and aquatic groups (**212**).

These characters however are too fundamental to

be explained as the result of convergence, and the distinction between aquatic (branchiate) and terrestrial (trachęate) arthropods breaks down when we remember that animals with either kind of habit must be included in the single class of the Arachnids. It is desirable therefore to look for points of affinity beween Insects and Crustaceans. The Crustacea are a large and varied class, containing many orders, which are grouped into two great series. The Entomostraca include Crustacea with a very divergent number of segments and appendages, sometimes as many as thirty, sometimes as few as seven pairs being present. The higher orders of Crustacea, on the other hand, are grouped together as the Malacostraca which, without exception, appear to be composed of twenty[1] primitive segments, whereof nineteen carry paired limbs. A head region with two pairs of feelers, a pair of mandibles, and two pairs of maxillæ, is very general among the Crustacea. The reader will hardly need to be reminded that the ancestors of the Insects and Arachnids in all probability were animals with twenty segments and nineteen pairs of limbs, whereof the first two pairs were feelers; of these the Insects, Centipedes and Millipedes, have lost the second pair, the Arachnids both

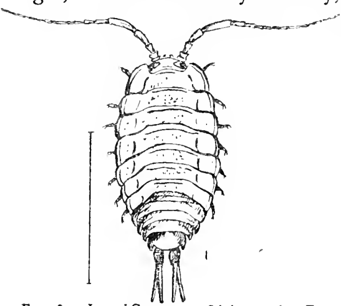

FIG. 183.—Isopod Crustacean, *Ligia oceanica*. From Scharff, Irish Nat., vol. 2.

[1] In all cases the number of segments stated does not include the procephalic lobes, or pre-oral segment (in front of the primitive mouth).

pairs. In the lower Malacostraca (Amphipods and Isopods) the first pair of thoracic limbs become an extra pair of maxillæ, so that there are four pairs of true jaws. According to a recent interpretation of the mouth-parts of the Collembola and Thysanura (**213**) this state of things finds an exact parallel in the jaws of those two lowly orders of insects. Though this view has not met with general acceptance, no doubt can be thrown on the accompanying observation that the mandibles of the Collembola and Thysanura, both in form and muscle attachments, resemble the mandibles of Crustacea more nearly than they resemble the mandibles of higher Insects. In any case the near and probably identical correspondence in the number of segments in Insects, Arachnids, and the higher Crustaceans, is too marked to be the result of chance; it must point to a far-off common origin for the three classes. And the retention of feelers, together with the correspondence in the head-segments, seems to show that the Insects are really nearer to the Crustaceans than to the Arachnids. Among the air-breathing arthropods the classes Chilopoda and Diplopoda show great variation in the number of their segments, while the more highly organised Insects and Arachnids can be clearly traced to an ancestor with twenty. So among the Crustacea, the lower orders (Entomostraca), seem to have arisen by an increase or reduction in the twenty segments which remain constant in the higher orders. A group of Crustaceans (Leptostraca), with an extra limbless segment to the hind-body, are in many respects intermediate between the Malacostraca and Entomostraca. This group, which had many representatives in the Cambrian period, is now reduced to a few forms only.

The probable correspondence (*homology*) between the segments and limbs in the various arthropod classes is shown in the accompanying table.

Post-oral Seg-ments.	Insecta (Cockroach).		Symphyla.		Chilopoda.		Diplopoda (Spirobolus).		Post-oral Seg-ments	Arachnida (Scorpion).		Crustacea (Crayfish).	
1	Feelers	Head	Feelers	Head	Feelers	Head	Feelers	Head	1		Cephalo thorax	1st Feelers	Head
2	Embr. App.		?		Embr. App.		?		2	Embr. App. (Spider)		2nd Feelers	
3	Mandibles		Mandibles		Mandibles		Mandibles		3	Mandibles		Mandibles	
4	1st Maxillæ		1st Maxillæ		1st Maxillæ		Maxillæ		4	Maxillæ (Pincers)		1st Maxillæ	
5	2nd Maxillæ		2nd Maxillæ		2nd Maxillæ		Embr. seg.		5	1st Legs		2nd Maxillæ	
6	1st Legs	Thorax	1st Legs		Poison jaws		1st Legs		6	2nd ,,		1st Maxillipeds [1]	Thorax
7	2nd ,,		2nd ,,		1st Legs		2nd ,,		7	3rd ,,		2nd ,,	
8	3rd ,,		3rd ,,		2nd ,,		3rd ,, (*Gen. op.*)		8	4th ,,		3rd ,,	
9		Abdomen	4th ,, (*Gen. op.*)		3rd ,,		4th ,,		9	Genital operc.	Abdomen	Great Pincers	
10			5th ,,		4th ,,		The succeeding segments (indefinite in number) become fused in couples.		10	Pectines		1st Legs	
11			6th ,,		Number of segments and legs indefinite. Genital opening on last segment but one.				11	1st Lung-books		2nd ,, *Oviducts*	
12			7th ,,						12	2nd ,,		3rd ,,	
13			8th ,,						13	3rd ,,		4th ,, *Vas. def.*	
14			9th ,,						14	4th ,,		1st Swimmerets	Abdomen
15	*Vagina*		10th ,,						15			2nd ,,	
16			11th ,,						16	1st Tail-segment		3rd ,,	
17	Stylets, *Vas. def.*		12th ,,						17			4th ,,	
18			Reduced limbs						18			5th ,,	
19	Cercopods		Cercopods						19			6th ,,	
20	Anal Segment		Anal Segment						20	Anal Segment		Telson (Anal Seg.)	

[1] These are an extra pair of maxillæ in Isopods and Amphipods. Possibly (**213**) they correspond with the 2nd maxillæ of Insects, if four pairs of jaws are present in Collembola and Thysanura.

Malacopoda.—Opposition to the common origin of Insects and Crustaceans from a primitive arthropod stock has largely rested on the supposed near relationship of Insects to a small class of worm-like animals, the Malacopoda (**61, 217**), comprising only a single family (Peripatidæ). These animals, which have a remarkably discontinuous range in the tropics and the southern hemisphere, have a head with a pair of feelers, a pair of mandibles and a pair of papillæ, and a body with from seventeen to more than forty segments, provided with pairs of imperfectly-jointed, clawed limbs; the skin is soft and covered with small tubercles. On account of the legs, the reduced coelom, and the heart with paired openings, these creatures are reckoned as arthropods, but they show several markedly worm-like characters—for instance, a pair of kidney tubes (nepridia) in each segment. They breathe by tracheal air-tubes, and, if it be granted that they represent the ancestors of insects, it can hardly be denied that Insects have arisen independently of Crustaceans, from the original ringed worms. But, as we have seen in the case of insects and arachnids, tracheal air-tubes do not prove affinity. Instead of regarding the Peripatidæ as the survivors of the ancestral stock of Insects, it is more satisfactory to consider that they represent an attempt at terrestrial life on the part of the very far-off ancestors of the whole arthropod branch. They must have taken to the land before those worm-like characters, which became lost in the common aquatic stock of the Arachnids, Crustaceans, Millipedes, Centipedes, and Insects, had disappeared (**215**).

Arthropods and Annelids.—A discussion of the relationship between the whole Arthopod Branch and the ringed worms (Annelida) cannot be attempted here. It may be mentioned that the limbs of arthro-

pods are probably comparable to the false feet or *parapodia* of marine worms, and that tracheal air-tubes may have originated from skin-glands. The genital ducts of arthropods are almost certainly to be regarded as modified kidney-tubes (nephridia) which have been retained in various segments in the different classes (**216, 217**). It may be doubted, however, if the most highly organised of living worms should be regarded as representing the ancestors of Arthropods. And if the suggestions of this chapter as to the relationships of Insects, Crustaceans, and Arachnids be justified, the immediate ancestors of the Arthropods cannot have been, as commonly believed (**216, 217**), "richly segmented" animals.

Origin of Insects.—Our comparison of the insect-orders with one another, and of the Class with other classes of arthropods, enables us to trace to some extent the history of the group. We look back to a time far earlier than the oldest of our fossil-bearing rocks and imagine the primitive arthropods—marine animals with twenty segments, whereof nineteen carried paired limbs. Already the first two pairs were specialised as feelers, the third as mandibles, the fourth as maxillæ. From this ancient stock the ancestors of the Crustacea branched off, retaining both pairs of feelers; the number of segments varied immensely in the Entomostraca, but remained constant, the form and function of the limbs becoming highly modified, among the Malacostraca. Another group, losing both pairs of feelers, and taking for the most part to life on land, became the primitive Arachnids. A third group, also taking to a terrestrial life, but losing only the hind pair of feelers, were the progenitors of Centipedes and Insects. If the Millipedes also sprang from this stock they must

be a very divergent shoot; more probably they had a separate origin. The air-breathing ancestors of Centipedes and Insects agreed with the Crustacean and differed from the Arachnid stock in having the fifth pair of appendages, like the fourth, used as maxillæ; the first five segments forming a well-marked head. The Centipedes diverged from these ancestors by a multiplication of segments, retaining the paired legs on each. The Insects, like the Arachnids, underwent a reduction in the size of the limbs on the segments behind the eighth; those on the seventeenth and nineteenth remained as stylets and cercopods, and a marked differentiation between the fore-body with its six legs and the hind-body resulted. The fusion (probably in an early ancestral form) of the eleventh with the tenth abdominal segment began that compression of the hind-body which is so marked a feature in the higher insect orders. The acquisition of wings (whose origin can only be guessed at) made Insects the leading class of land-invertebrates, and ultimately brought about the wonderful transformation of the higher insects, as we have already seen (pp. 356-8). The accompanying table (fig. 184) in which the probable history of Insects and the other arthropod Classes is shown in graphic form, may serve to summarise the conclusions of this chapter.

Age of Insects.—The most striking thought suggested by the history of Insects is their vast geological age. In the Secondary Epoch, when the mammals, now the dominant class of land-vertebrates, were small and struggling, and orders of huge reptiles now quite extinct, lorded it on the continents, insects of the highest orders living to-day—Lepidoptera, Diptera and Hymenoptera—were already flying through the air. We must go back into the Primary

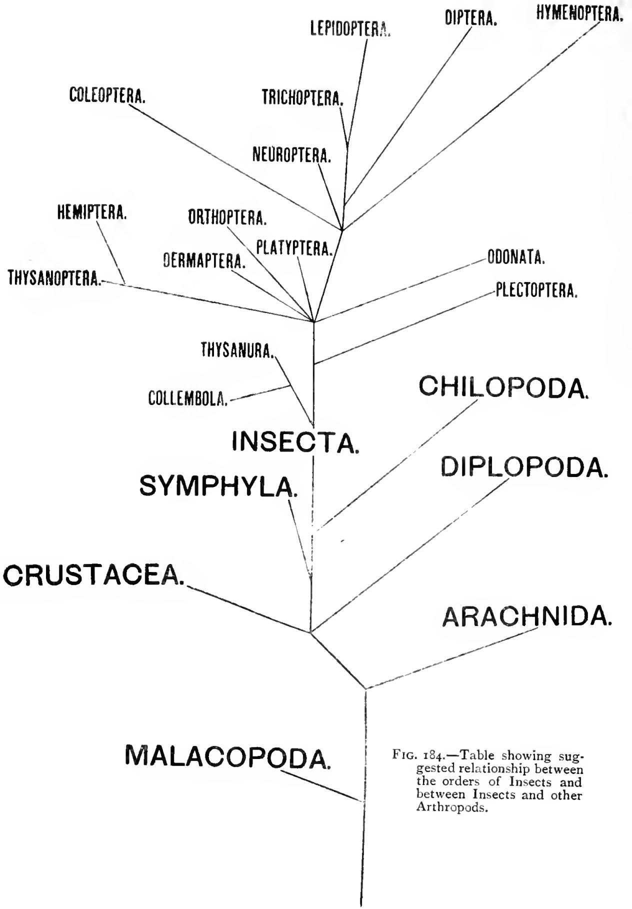

FIG. 184.—Table showing suggested relationship between the orders of Insects and between Insects and other Arthropods.

Epoch for the oldest metamorphic insects, and we know that so early as Devonian and even Silurian times winged insects like the Cockroaches and Termites of to-day, inhabited our earth. The Ordovician is the latest of the great periods in which the ancestors of insects can be supposed to have taken to the land; and in the preceding Cambrian age we are face to face with the oldest known fossils, which prove that the lower Crustacean types were even then already well established. To what an immensely remote period then must the primitive arthropods have belonged!

We often take mountains as emblems of age and speak of the "everlasting hills." The most advanced orders of insects are older than the chalk of the southern English downs, while the early winged insects flitted by the shores of the lakes wherein the grits and sandstones of the Kerry Reeks gathered fragment by fragment. For the primitive wingless insects we must look at least to the time when by accumulation of coral, and the ash and lava of old volcanoes, the rocks of Snowdon were being slowly formed on the bed of the Primary Sea. And the oldest rocks of the Western Highlands of Scotland will hardly carry us back to the primeval arthropods. We walk over the hills rousing the bee from the flower, or the dragonfly from the rushes. The life of each individual insect lasts but for a few days, or months, or years. Yet these creatures are the latest links in a long chain of life which reaches back to a time before the mountain whereon they dwell was brought forth. To unobservant eyes the landscape seems enduring, but study of its features shows that it changes from age to age, changes even more rapidly than the insect-types which adorn it. Yet through the long periods of the

earth's history the insects have been changing too; and the form of their bodies, and the history of their growth, teach us how to trace in some degree the wondrous unfolding of their branch of the great tree of life.

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